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ARTESIAN WELL SECTIONS AT ITHACA, N. Y.[1]

THE WELLS.[2]

During the typhoid epidemic at Ithaca, N. Y., in 1903, a committee of citizens began explorations for a source of artesian water to replace the surface supply then in use. This work was continued by the Ithaca water board, and the result was the sinking of thirteen wells in a limited area on the southern outskirts of the city. Prior to this an artesian well had been developed in the same area, yielding a daily flow of about 300,000 gallons from a series of Pleistocene gravels at a depth of about 280 feet. A majority of the new wells found water in what appear to be the same gravels; others failed to develop water.

Besides these deep wells, there are a large number of shallower ones in the city of Ithaca which obtain artesian water in a gravel series found at depths usually from 50 to 100 feet.

[1]Published by permission of the Director of the United States Geological Survey.

I am indebted for valuable assistance in the preparation of this paper to the following gentlemen: Mr. C. C. Vermeule, engineer in charge of the boring of the wells, for directing that samples be preserved for me; Mr. F. L. Getman, his assistant, for collecting the samples and for other valuable information; Mr. Lawrence Martin, of Cornell University, for aid in gathering information, and in consideration of the nature of the well sections; Dr. G. K. Gilbert, for placing at my disposal certain facts from his notebooks bearing upon the question of tilting of the land in central New York; Dr. William H. Dall, for identifying the mollusca; and Professor D. P. Penhallow, for identifying the plant remains.

[2]A more detailed statement of the bearing of this exploration on local water supply will be published by the U. S. Geological Survey.

IMPORTANCE OF THESE WELLS.

These wells have yielded three important geological results: (1) They have in two cases revealed the exact depth of filling by Pleistocene deposits, and have therefore given some additional facts concerning the form and depth of the Cayuga Valley. (2) Since samples were collected at frequent intervals in several of the wells, and records kept of all, they have revealed the structure underlying the Ithaca delta down to the rock floor. (3) They have thrown some light on the occurrence of artesian water in Pleistocene deposits.

DEPTH OF DEPOSITS.

The wells are all located near the western margin of the delta on which the main portion of the city of Ithaca is built. The surface soil is clay and muck, and the region is evidently one reclaimed from Lake Cayuga by the same processes of lake filling that are now at work on the outer edge of the delta on the north side of the city. While low and swampy throughout much of its area, this nearly level delta rises perceptibly toward the creeks that descend through gorges cut in the valley walls. These elevated sections are low, flat alluvial fans, raised above the general delta level by deposits brought down by the torrential streams that occupy the hillside gorges.

The delta also rises gently toward the south, and at a distance of about two miles south of Ithaca abruptly ends against the north face of the morainic complex which fills the valley thence to its present divide. It is evident that this moraine descends beneath the delta deposits.

Two of the borings reached bed-rock, one (Fig. 1, *C*) at a depth of 260 feet, the other (Fig. 1, *G*) still further out in the valley, at a depth of 342 feet. A profile of the valley at this point is shown in Fig. 2. Farther north (Fig. 1, *A* and *B*) two wells, bored to the underlying salt, encountered rock at 430 and 401 feet respectively, the latter being 1,500 feet south of the former.

These borings are not numerous enough to warrant any conclusions further than that the maximum depth of the valley is at

least 430 feet below the delta at Ithaca, or about 25 feet below sea-level. Since soundings in Lake Cayuga reveal a depth of 435 feet in the deepest point, in which, of course, there is at least some filling, the borings at Ithaca do not add to the known depth of the valley. It is not to be inferred, however, that the deepest boring at Ithaca, although near the middle of the valley, really represents the deepest part of the valley in this region.[1] The discovery of rock in these wells shows that the general slope of the lower valley walls is continued down with practically no change (Fig. 2), at least to the depth reached in the artesian wells (Fig. 1, *C* and *G*).

FIG. 1.—Section of the "Ithaca Sheet" (U. S. Geological Survey) to show the location of the artesian wells. *A*, *B*, salt wells, rock at 430 and 401 feet respectively; *C*, Strang Well, No. 1, 286 feet, struck rock at 260 feet; *D*, Millard Well, No. 2, 259 feet; *E*, Old Clinton St. Well, 280 feet; *F*, South Well, 232 feet; *G*, Strang Well, No. 2, 352 feet, struck rock at 342 feet; *H*, Trapp Well, 332 feet; *I*, Holmes Well, 291 feet; *J*, Millard Well, No. 1, 303 feet; *K*, several wells, close together, as follows: Illston Well, 286 feet; Strang Well, No. 3, 280 feet; Strang Well, No. 4, 279.9 feet; Strang Well, No. 5, 276 feet; and Strang Well, No. 6, 295 feet; *L*, Millard Well, No. 3, 303 feet.

DESCRIPTION OF THE WELL SECTIONS.

Both in the deeper artesian wells and in shallow ones in the city of Ithaca the upper layers are found to be a fine-grained, massive clay. In two cases it is reported as sandy. This clay layer is absent, or at least not continuous, near the eastern wall of the valley where alluvial fans have been built opposite the stream mouths. The depth of the clay stratum varies from approximately 40 to 60 feet. Fragments of mollusca and plant fragments, including pieces of reeds and wood, were found in several of the samples from this clay layer; and in two cases logs were encountered, one at 38–39 feet, another at 33 feet.

[1] It is noteworthy, in this connection, that a well near the center of the Seneca Valley at Watkins had not reached the bottom of the drift deposits at a depth of 1,080 feet.

Beneath this clay layer, in every well of which there is a record, a series of coarser beds is found. These coarse beds vary greatly even in neighboring wells; but in most cases there are both sand and gravel layers. The bottom of the series of coarse sediments varies from 60 to approximately 120 feet, and the thickness in individual wells from 20 to about 70 feet. The coarser sands are clear and well washed; the gravels consist of well-rounded pebbles similar to those now brought down by the torrential creeks that enter the valley.

In most of the samples preserved from these coarse layers plant fragments and mollusca were found. Seven logs were encountered, and the two logs found in the overlying clays were almost down to the level of the coarser series. Thus between the depth of 35 and 119 feet nine logs were encountered in boring thirteen six-inch wells. Since two of the wells passed through two logs each, logs were encountered in seven out of thirteen wells. The depth of the several logs is given in the following table:

Wells	Depth in Feet	Material
Strang	56 –58	Gravel
Old Clinton St	63	Sand
Millard 3	38 –39	Clay
Millard 3	118 –119	Sand
Trapp	48½–50½	Gravel and sand
Trapp	55½–56½	Gravel and sand
Millard 1	50 –51½	Sand and pure gravel
South	33	Clay, somewhat sandy
Strang 3	110 –112	Probably at bottom of gravel

In all the deep wells the coarser layers are underlain by a great thickness of clay, in which no molluscan remains were found, though in several samples small, indefinite plant fragments occur. In most of the wells the driller failed to preserve more than one sample, which he considered typical of the entire clay mass; but near the top and bottom of the series the material is occasionally reported as "clay and stone," "clay and gravel," or "clay and sand." In one well (the south well), however, samples were preserved every ten feet, and these samples show clearly the nature of the material. From top to bottom, that

is, from 70 to 200 feet, it is a fine-grained clay, at all depths lower than 100 feet containing small angular pebbles, in some cases scratched. These stones increase in number and size toward the bottom, and the proportion of sand increases to such an extent that below the depth of 135 feet the well-driller calls it a sandy clay. But down to the 200-foot level the stratum is unquestionably clay.

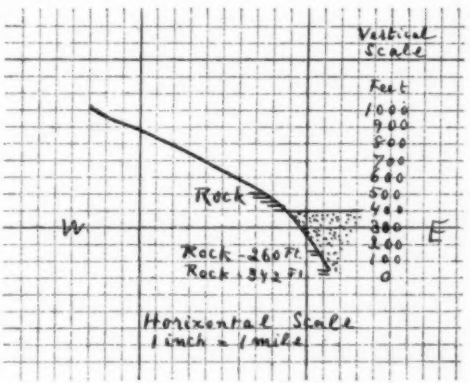

FIG. 2.— Profile of the hill slope on the western side of the Cayuga Valley at Ithaca just west of the artesian well sites. This profile is continued down to the points where rock was reached in the artesian wells. (Horizontal scale, 1 mile to the inch; vertical scale, 1,000 feet to the inch.)

Owing to the indefiniteness of the nomenclature used by well-drillers, and the failure in many cases, to preserve samples it is not always easy to state exactly where the bottom of the clay series is. Using the best judgment possible, I place the base of the clay series in the thirteen wells as follows: 220, 210–30, 262–76, 238–78, 230, 225–76, 200, 214–80, 202–22, 244–70, 240, 242–46, 234–70. The well which gives the 200-foot level for the bottom of the clay is the one from which most samples were obtained, and for that point may be accepted as correct. It is, however, the farthest south of all the wells, and it does not follow that the bottom at that point is the same level as the bottom at other points. On the contrary, all the evidence seems to indicate that the base of the clay series is decidedly irregular.

As the base of the clay series is approached, and after it is certainly passed, a series of beds of marked irregularity is encountered. They are prevailingly coarse-textured, and in every well include some sand or gravel. In many of the wells

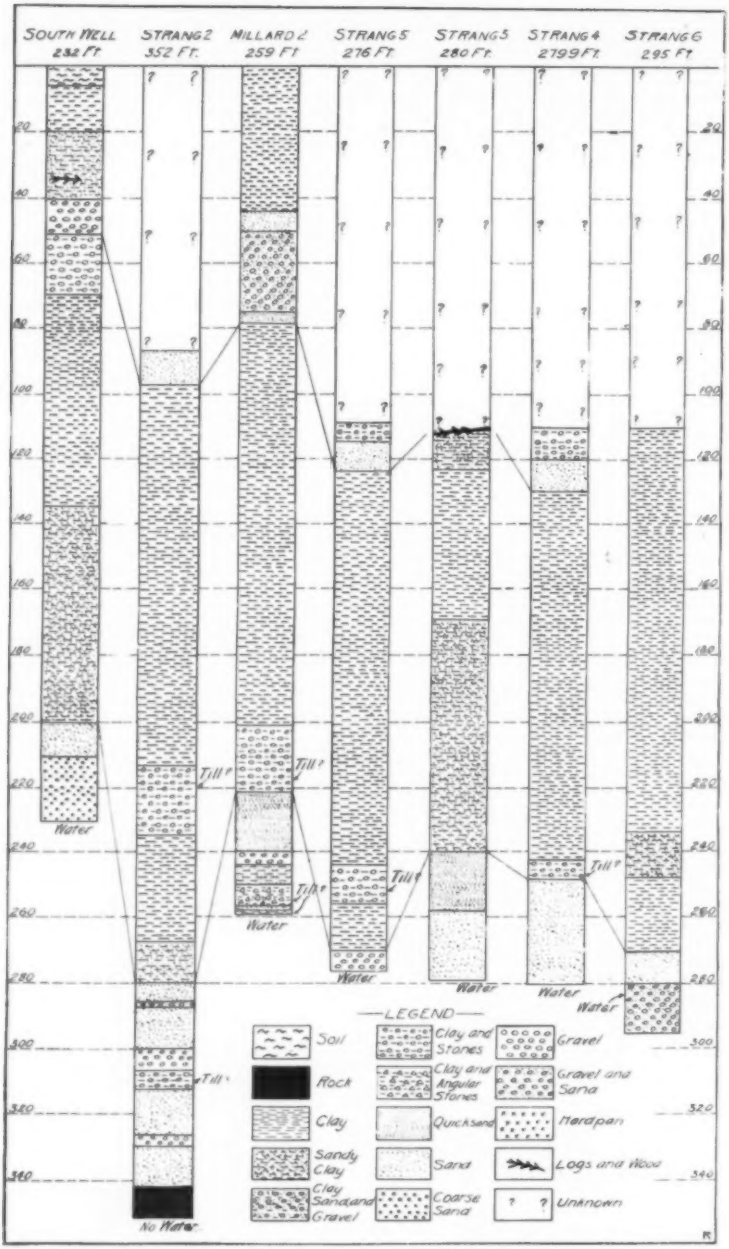

FIG. 3.—Sections of seven artesian wells grouped approximately along a north-south line. South well, southernmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

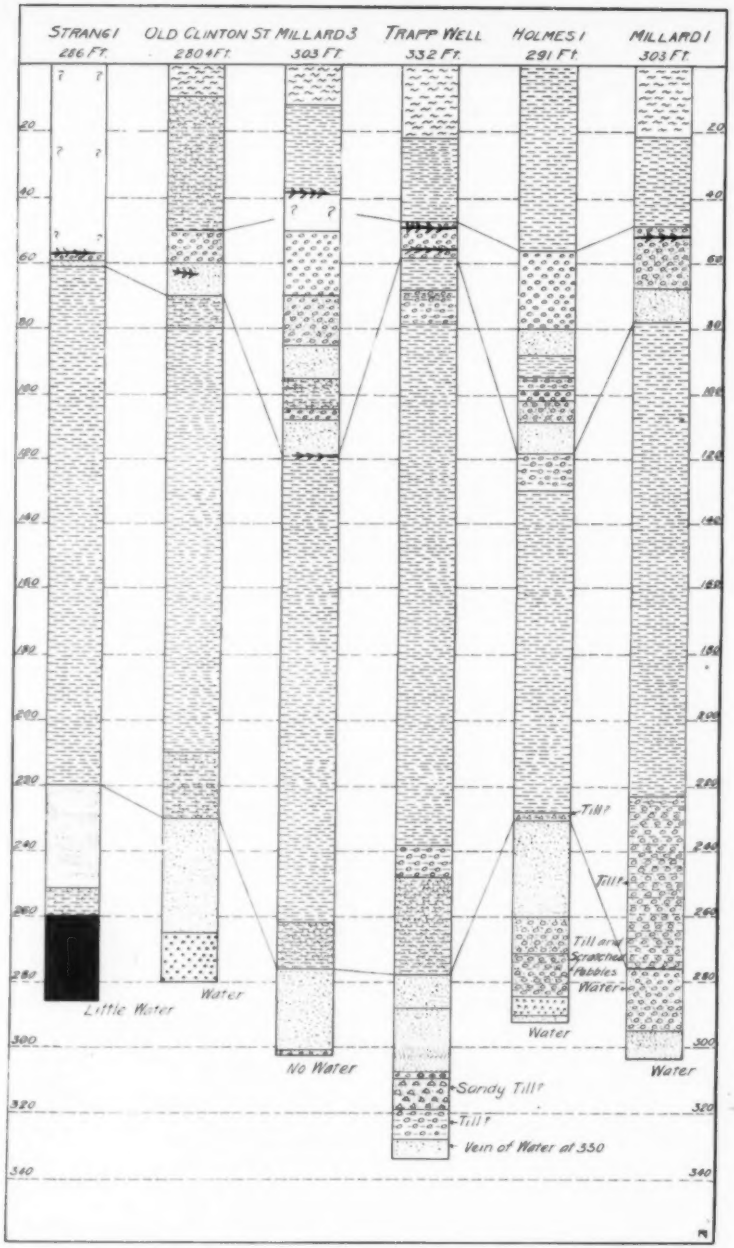

FIG. 4.—Sections of six artesian wells grouped approximately along an east-west line. Strang 1, westernmost; Millard 1, easternmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

both sand and gravel are encountered. No two of the wells have the same sequence of layers, even though the wells are close together. Samples prove that some of the layers are water-washed sand and gravel, while others are unquestionably till, with scratched stones. In a number of other places till is suspected, though the evidence is not sufficient to prove it.

In this series of coarse deposits, water is found at varying depths in the different wells, and in different sediments. In some cases it is found in a sandy clay, called "quicksand," in which there is so much water, under such pressure, that the sand is forced into the pipes in sufficient quantities to fill them and stop the water flow. Between this extreme and that in which the water is found in coarse gravel, there are several intermediate conditions. The largest flow is obtained from the coarse gravels.

Beneath the unquestioned till, and in various places beneath the materials interpreted as probable till, is found a black sand in which from 50 to 75 per cent. of the material is quartz, the remainder being mainly dark shale fragments. In one of the wells that reached bed-rock this black sand rests on the rock, which was encountered at a depth of 342 feet. Neither here nor in the other well that reached rock, nor, in fact, in any of the wells, was any older drift encountered. All the materials are such as might have been brought by the last ice advance, or deposited since the ice-sheet melted away. Whether deposits of earlier ice advances were never made here, or whether they were all swept away by the last ice advance, is not determined by the evidence.

INTERPRETATION OF THE WELL SECTIONS.

Morainic lower series.—The history of the accumulation of the 342 feet of sediment revealed by these well-borings is in most respects clear. That the bottom series of till, sand, and gravel is morainic seems proved by several facts: (1) the neigborhood of the massive moraine which rises above the delta two miles south of the wells; (2) the position of the coarse materials at the base of the series, from all other members of which they differ decidedly; (3) the apparently irregular outline of the

upper portion of this lower series of coarse materials; (4) the marked variety of materials composing the lower series, which vary from gravel and sand to till, thus closely resembling the moraine that rises to the surface farther south; (5) the large percentage of water-washed material, again resembling the condition in the moraine farther south. This large amount of water-washed material would be expected where the ice-front stood in a deep lake, as was the case here.

Glacial lake clay.—It is well established by the evidence of various overflow channels, by well-defined elevated deltas at various levels,[1] and by lake clays on the hill slopes, that the Cayuga Valley was occupied by a steadily expanding, ice-dammed lake, with its level frequently lowered as successively lower outlets were discovered by the melting back of the receding ice-sheet. This lake condition lasted for a long time; in fact, until the Mohawk outflow was discovered. The length of this period of lake stage cannot be stated; but it was sufficient for the ice to have melted back at least forty miles. Of necessity a great amount of clay must have been deposited in this lake, not merely that supplied from the glacier, but that washed from the hill slopes, and that brought by the streams which descended the steep hill slopes.

The great thickness of clay found in all the wells, usually between the 100 and 200-foot levels, is interpreted as lake clay deposited in this ice-dammed lake. The great thickness of the clay stratum, its uniform character, its occurrence in all the wells, the general absence of animal remains and the presence of only minute fragments of plants, the occurrence of scratched pebbles that might have been ice-borne, and the increasing coarseness of the clay toward the bottom, all harmonize with this interpretation. No opposing facts were discovered.

Recent lake clays.—The uppermost clay beds, between the 0 and 40–50-foot levels, with abundant organic remains and an almost complete absence of sand and pebbles, are interpreted as lake

[1] See papers by FAIRCHILD, *Bulletin Geological Society of America*, Vol. VI (1895), pp. 353–74; Vol. X (1899), pp. 27–68; and by WATSON, *New York State Museum Report 51* (1897), Part I, 155–117.

clays formed in the same manner as those now accumulating. They are believed to represent modern lake-filling similar to that now in progress at the head of the lake. When the number of torrential streams that descend the valley wall is considered, the amount of lake-filling which this stratum represents is not excessive. These streams have formed deep gorges, having not only removed much drift, but also cut deeply into the shale. The material thus removed seems ample to make this deposit.

The upper series of coarse sediments.—A much more difficult problem is presented by the sand and gravel series, sandwiched between the two clay beds, and covering an area whose length north and south is known to be over one and a quarter miles. Some widespread change in condition is here represented, indicating a stage during which clay deposit was interrupted, apparently after the ice-dammed lake ceased to offer opportunity for deposit of lake clay, and before conditions appeared which permitted the accumulation of the later lake clays.

This period of interruption of lake clay deposit must have been one in which, at the site of the wells, the conditions were either those of a shallow lake or else of absence of lake water. Both the coarseness of the sediment and the abundance of organic remains indicate this. It is inconceivable that at a distance of three-eighths of a mile (the distance from the outermost well to the nearest valley wall) gravel and sand could be deposited in a lake from 56 to 118 feet deep, especially at a point remote from the mouth of any stream. It is inconceivable, also, that gravel and sand could be deposited in such a lake over so wide an area. Nor does it seem probable that such a large number of logs would be accumulated in lake deposits. The chance discovery of seven logs in boring thirteen six-inch wells through this sand-gravel series indicates a large number of logs in the series. This point becomes all the more striking from the fact that only two logs were found in the recent lake clays, and both of these near the sand-gravel series, while no logs were encountered in the ice-dammed lake clays.

Professor Penhallow has determined the two specimens of wood preserved as follows: (1) South Well, 30–35 feet in clay,

Pinus rigida; (2) Millard Well No. 1, 50 feet, gravel, the common tamarack, *Larix americana.* Dr. Dall reports that the mollusca belong to the following genera: Valvata, Planorbis, Amnicola, and fragments of Pisidium or Sphœrium. These are

all of the same nature, namely fresh-water, and such as are found in the confervæ or other fine-textured vegetable matter, such as grow in quiet places in the course of brooks, or in ponds or lakes at the mouth of brooks. They would hardly be found in the unsheltered waters of a large lake like Lake Erie.

Correlation of coarse sediments with Iroquois stage.—The evidence seems conclusive that these sands and gravels were either shallow-water, lake-margin deposits or else stream-made land deposits, and that they were succeeded by lake conditions. In seeking for an explanation of these phenomena, land-tilting seems the only rational hypothesis. It is a well-known fact, as clearly shown by Dr. Gilbert, that the land has been tilted in this region since the deposit of the beaches of the Iroquois shore line. The Iroquois lake stage immediately succeeded the stage of ice-dammed lake in Cayuga Valley. Therefore these sands and gravels are in the right position for correlation with the Iroquois beach stage.

In a letter to me Dr. Gilbert supplies the following information: Correlating the upper bar at Richland Junction (563 feet) with the lowest bar at Weedsport, there is a gradient of 2.9 feet per mile. Correlating the upper Richland bar with the lower cut terrace at Montezuma, there is a gradient of 2.6 feet per mile. Correlating the upper Richland bar with a bar at Cayuga, there is a gradient of 2.7 feet per mile.

The lines on which these measurements are made do not precisely correspond with the direction of greatest slope of the plane of deformation, but I judge that the line from Union Springs to Ithaca makes about the same angle with the direction of greatest slope, so that these figures might be applied without correction. A correction for direction would increase the estimates for gradient.

From Union Springs, where the Iroquois beach disappears beneath Lake Cayuga, to the site of the wells is approximately twenty-nine miles; and, taking 2.7 feet per mile as a gradient, the Iroquois shore line might be expected to appear at Ithaca at a depth below present lake-level of about 78 feet. Several of

the wells passed through coarse material at this depth, and in several of them the coarse materials reach a much greater depth than this. On the other hand, the records of four of the wells show that the sands and gravels were passed through before that depth was reached. In his letter Dr. Gilbert makes this further statement:

> From Richland northward to Adams Center the gradient is 4.3 feet per mile, and north of Adams Center it is still steeper. So it is possible that a correction might advantageously be applied to southward flattening of gradient.

Some such correction, the exact amount of which is not clear, would seem to harmonize better with the distribution of the gravels as revealed by the well sections.

Several facts, as follows, seem to warrant correlation of these deposits with the Iroquois stage: (1) the difficulty of otherwise explaining the sand-gravel series; (2) the evidence of coarseness of material, and of plant and animal remains, all of which point either to land or shallow-water conditions; (3) the position of the series, resting on deposits which appear to have been completed just before the Iroquois stage; (4) and the fact that their position is approximately at the level to be expected on the theory of formation during the Iroquois stage. No facts opposing this correlation are known, and no other rational explanation suggests itself. It is therefore proposed as an interpretation of the phenomena.

SUMMARY OF EVENTS.

On the basis of these interpretations, we have revealed the following postglacial history of the Ithaca delta: First moraine was formed while the ice-front stood in a deep lake, in which the morainic material was largely assorted. After this stage there was a long period of lake clay deposit in an ice-dammed lake whose area was expanded, while its level fell by successive drops to lower levels as the steady melting back of the ice-front discovered lower and lower outlets to the north. In this lake there was floating ice, but little, if any, animal life. When the Mohawk outlet was finally discovered the ice-dammed lake nearly, if not quite, disappeared from the site of the artesian wells. The

land surface at the site of these wells was then from 60 to 120 feet below the present delta surface; but, owing to the depression of the land in the north, the lake waters either could not then reach this far, or, if they did, produced only a shallow lake. At this stage trees grew and mollusca thrived, while a series of sand and gravel layers were laid down whose depth in the several wells varies from 20 to 70 feet.

Elevation of the land in the north tilted the basin of Lake Cayuga faster than the deposit of sand and gravel was made, ultimately covering the coarse deposits with lake water. Some of the sand and gravel may be due to the work of the lake waves as the tilting of the land caused an encroachment of Lake Cayuga farther and farther south. The fact that the present surface of the delta contains no sand and gravel excepting near the stream mouths, may be explained as follows: (1) the levelness of the delta; (2) the recency of the delta—it is still so swampy at the well sites that it is flooded at least once each year; (3) the fact that the streams now bring less material, having already cut through the drift into the rock.

SOURCE OF THE ARTESIAN WATER.

It is believed that the source of the water in the upper gravels is the alluvial fans opposite the mouths of the streams that descend to the Ithaca delta. Into these fans much of the stream water sinks, in some cases entirely disappearing at all times excepting in periods of flood. It is not absolutely certain that the gravels of the alluvial fans are continuous with the sand-gravel series encountered in the shallower artesian wells; but this is to be expected, since the conditions which favor the deposit of coarse sediment must have existed continuously near the mouths of the streams that descend the hill slope. Some such source near at hand is indicated by several facts: (1) a reported variability in volume; (2) the moderate pressure of the wells, which in some cases barely forces the water from the ground; (3) the composition of the water, which indicates a shorter underground journey than that of the water in the deep wells; (4) the marked difference in composition and purity of the water from various wells.

For the water found in the deeper sands and gravels the source is believed to be the moraine which occupies the Cayuga Valley from the divide nearly to the well sites, a distance of over eleven miles. Numerous streams descend to this moraine, supplying much more water for percolation than the mere rainfall. The moraine is to a very large degree made of sand and gravel, offering the best of conditions for the entrance of water. The hardness of the water and the temperature (52° in August and December) both indicate a long underground journey; and the great pressure, which forces from one of the wells a steady volume of 300,000 gallons a day, also indicates some fairly distant source. To account for the pressure observed it is necessary to find a source much higher than the well sites. No such source is to be found to the north because the lake occupies that region; to the east and the west rise high hills in which are nearly horizontal strata of shale and sandstone. This leaves the moraine to the south as the only possible source of the water; and this source is not only ample, but, if the above interpretation of the well sections is correct, there is a direct connection between the surface moraine and the buried moraine gravels which supply the water.

R. S. TARR.

ITHACA, N. Y.

THE RÔLE OF POSSIBLE EUTECTICS IN ROCK MAGMAS.

THE appearance of Professional Paper No. 18, *The Chemical Composition of Igneous Rocks, Expressed by Means of Diagrams*, by Professor Iddings, completes a trilogy of works[1] which will leave a permanent impression upon the nomenclature and progress of petrography. No one who has not done a little work of the sort can begin to conceive of the amount of labor employed in the comparatively small paper of less than one hundred pages which has just appeared. And even so, it is probable that vastly more in the way of experiment in trying to group the facts in different arrangements has been done, of which no trace remains. We see the finished railroad survey, and can form some conception of the engineering, but we cannot know how many lines may have been run through the dense forests before settling upon the final track.

It is easy also to notice possible improvements in the track when it is once completed; and if I make some suggestions along this line, it is only with the greatest respect for the distinguished authors of the new chemical classification. Whatever modifications the future may have in store, I think that there will be much of their work which will endure, and that such terms as "persalic" and "dofemic" will after a little become household words to the petrographers of all countries. I think the remark of Mr. Iddings, that we must look upon a rock as the chemist looks upon a solidified mass of mixed salts, that "we must think of the study of igneous rocks, their magmas and relationships, as purely physico-chemical problems, involving the measurement and comparison of mass and force, and their definite quantitative expression," as one of very great importance. When he goes on to say that there are no recognizable groupings of

[1] *The Quantitative Classification of Igneous Rocks*, by CROSS, IDDINGS, PIRSSON, AND WASHINGTON, and Professional Paper No. 14 by WASHINGTON, being the two previous works.

rocks or noticeable subdivisions of chemical series, that chemically similar rocks occur in genetically different families, that it follows that the subdivisions of all igneous rocks into groups for the purpose of classification must be on arbitrarily chosen lines, and that it is no argument against a classification if a rock of great importance belongs on the boundary of a classificatory division, that any system of classification will be as natural as any other system, he is rather too pessimistic. Merely as a mass of mixed salts, there are certain common relationships which hold, and of which any system of classification, the new one included, must take account. He has pointed out a number of such facts: (1) In the great majority of rocks alkalis do not exist in excess of that required to make feldspar or nephelite; (2) The commonest rocks are in composition like the average of all rocks which has the silica percentage of 58.7 to 59.77 and an alkali-silica ratio of 0.083 to 0.088. Iddings, in fact, suggests the possibility that all rocks have been derived from one common magma by splitting. If so, this splitting must have gone on under chemical and physical laws which are to be traced and followed in the classification. There is, however, another possibility which I wish to suggest, namely, that in the process of splitting there is a tendency in one of the fractions toward that same common average.[1] To this point we will return later. There are numerous other facts which Iddings points out, such as the inverse relation between silica and alkalis, and iron and magnesia, and various other notes on pp. 19, 64, 65, 70–81, of which any classification may take account, as, in fact, the new one does, to a very large degree. Upon that depends its serviceability. The fact that there are exceptions does not invalidate the importance of this relation, provided they are not too many.

Now, if one looks over the general diagram, Plate I, which Iddings has prepared to see that it is true that there is "no clustering of analyses" and "no natural subdivisions" (p. 17), I cannot agree with him in the conclusion he draws. In the first place,

[1] This would fit especially well in a planetesimal theory; in fact, would be almost necessary in view of the wide prevalence of basaltic magmas.

as he himself has pointed out, there are no more alkalis in most rocks than alumina and silica to go with them. In the second place, there are very few rocks with high silica percentage down about to the point representing the average rock in which the ratio of alkali-silica is less than 0.04. As the amount of alkalis increases, the number of analyses becomes more numerous. Somewhere between the ratios 0.08 to 0.09 they are most abundant. After that they diminish somewhat and become less up to a ratio between 0.12 and 0.16, and then they become more numerous once more. If we suppose this not to be accidental, we must assume *a tendency on the part of a certain group of magmas toward an alkali-silica ratio between 0.08 and 0.09*. I fixed on 0.083 from the diagram. This, I noted, was the ratio of the average rock. Expressing this in fractions, the alkali-silica ratio would be 1:12. This suggested to me at once a combination of orthoclase or albite and quartz with equal molecular proportions of silica. This again reminded me of Rosenbusch's spherulite-forming microfelsite, which he supposes to be of the composition $K_2O \cdot Al_2O_3 \cdot x\ SiO_2$, with x greater than 6. It is also the composition of micropegmatite where the quartz and feldspar are equal. All these facts harmonize with the supposition that the combination $(Na_2O, K_2O) \cdot Al_2O_3 \cdot 6SiO_2 + 6SiO_2$ is the eutectic ratio of alkali and silica. If such magmas are composed mainly of alkalis, alumina, and silica, these will tend to crystallize out whichever of these components happens to be in excess, and the analyst will be likely in the long run to obtain more analyses near this ratio than either above or below. This supposition is obviously compatible with the idea that the igneous rocks are derived from fusion either of pre-existing sedimentaries or of planetesimals.

We have remarked that down to where silica equals 0.59 and 0.57 there seems to be a belt of analyses having about this ratio, with comparatively few as the ratio dropped. Now, of course, these rocks are not all simply feldspar and quartz. How do we explain this belt or line? Simply by supposing that this eutectic relation holds, even though other elements were combined with the silica, that the 6 silica may be more or

less in combination with other elements commonly occurring in rocks, and yet that the eutectic ratio of alkali:silica :: 1:12 would hold true. Possibly it must be in combination with H_2O or some other oxide.

The first element, of course, to be considered would be the lime. What composition of albite and anorthite would give the same eutectic ratio? A little simple algebra proves that it is the commonest labradorite (Ab_2 An_3). Now, this feldspar is, as we all know, one of the commonest in rocks, and more easily fusible than either albite[1] or anorthite, so that it is strictly eutectic. In other words, the diagram seems to show that there is probably a eutectic series from a micropegmatite with quartz about equal to albite or orthoclase down to labradorite. If this theory is true, then there would be a tendency in rocks where the alkali-silica ratio was less than 1:12 to have the silica crystallize out first in a porphyritic way as quartz; and, on the other hand, if the alkali ratio were a little greater, there might be a tendency to have the feldspar crystallize out early, so as to bring the residual magma down to the eutectic ratio. A large excess of alkali would bring it near another eutectic. Corresponding to these would be a more or less quartzose marginal zone where the crystallization first began. That this is liable to be modified more or less by irregular changes in temperature, pressure, and environment, I need hardly add.

But what about the other elements, in particular the iron and magnesia? If silica were there in excess of the eutectic ratio, they would combine with it very easily and, such compounds being relatively insoluble in the magma, crystallize and separate out, in sharp form embedded in the eutectic compound. In harmony with this, we find some of the few analyses which are markedly below the eutectic ratio containing considerable quantities of lime, magnesia, and iron. They may be aggregates of these earlier eliminations of the magma—divergent splits. Some of them are such, I judge from the description. Moreover, the minerals formed in such magmas must have high silica ratios, be augite or enstatite rather than olivine.

[1] According to the latest researches of Doelter and others this is not so—for albite is 10° to 15° more fusible.

We have remarked that the eutectic ratio continues in a line from micropegmatite to labradorite ($Ab_2\ An_3$). This feldspar has a silica percentage of 53 and an alkali-silica ratio of 1 : 12. This is so close to the ratios of the average rock that they are within the limits of the probable error; in fact, we may say that the average rock has the same silica percentage and alkali ratio as labradorite. Now, we will notice upon the chart that once the silica falls below this ratio there is marked change in the behavior of the analyses, and they seem to stream off toward the lower right-hand corner, the alkali ratio dropping with the silica ratio. We might infer, therefore, that for rocks less silicious the eutectic ratio above given did not hold; or, rather, it may hold, so far as the alkalis are concerned, that they still find the most fusible compound $Na_2O \cdot Al_2O_3 \cdot 6\ SiO_2$, and $6\ ROSiO_2$, but that in the presence of an excess of bases there is some other equally or more fusible compound $ROSiO_2$.

This, remember, is a purely theoretic inference from laws of chemistry and Iddings's diagram. A moment's thought shows how amply it is confirmed by petrographic research. This more fusible mineral is augite. As the percentage of SiO_2 in augite is about the same as in labradorite (between 55 and 44), and cannot anywhere in the pyroxene group get above that of enstatite (60), we see why the distribution of analyses turns a square corner, and we find them quite frequently from 0.58 SiO_2 down with all kinds of alkali ratios. We may go on to ask if there is any eutectic balance between labradorite and augite. As the ratios of lime to silica and percentage of silica are practically the same in the augite and in the labradorite series, the question as to the predominance of the one or the other tendency will probably be a question of balance mainly between the femic and alkaline constituents. The femic constituents in a magma mainly of felsitic eutectic are only slightly soluble and tend to crystallize out early as magnetite, biotite, hornblende, etc., even though present in very small quantities; and even though they increase markedly in abundance, their solubility or fusibility is still small, except as they can be taken into the augite molecule. An excess of magnetite or olivine crystallizes readily.[1] The metallurgists tell us

[1] I am neglecting a lot of minor matters.

about this in their slag formulæ. Consequently, it is *a priori* probable that labradorite and augite magmas mix readily and without tendency to split; though, when they actually come to crystallize, petrographic observation teaches that the labradorite feldspar is the earlier and the augite later for the rocks on the right or lower silica side of the average rock. The reverse is true on the other side. We must remember that, so far as chemical affinities allow, the eutectic (most fusible, least solidified) magma will contain a little of every element going; and therefore we are not surprised at the complexity of the composition of the augites which are collected in the table accompanying the statement of the *Quantitative System*. The latest researches show that basaltic magmas are fusible at distinctly lower temperatures than either labradorite or augite.

Nor are we surprised that, if we draw a line from the average rock-analysis point, or that for labradorite, in the average direction in which the less silicious and less alkaline analyses diverge therefrom, it will strike the line of no alkalis at 43 per cent. SiO_2, or somewhat less; for this is not only the lowest silica percentage which augite, diallage, and the feldspar series reaches (anorthite), but the maximum for olivine.

So in the femic magmas there is a clear tendency away from extremely different percentages of iron, lime, or magnesia. Probably the ratio CaO : MgO : FeO :: 2 : 1 : 1 is not far from the eutectic one. In the following group of analyses from Lighthouse Point, for instance, it is clear that at the center, where there was opportunity for differentiation and adjustment of the magma, and the eutectic would accumulate, there is more lime than at the quickly chilled and cooled contact. The magma had an excess of magnesia and iron for eutectic relations, and this is shown petrographically by an early generation of olivine and magnetite.

Returning to the Iddings's diagrams, it seems, from a study of the distribution of Class I, that a few rocks are included (anorthosites, canadases) which it goes against the grain to include—rocks with an unusual amount of lime, but really tributary to the femic eutectic; that the real natural family is from

ANALYSES OF STONE FROM LIGHTHOUSE POINT, UNDER DIRECTION OF E. D. CAMPBELL, BY E. E. WARE, JUNE 30, 1903.

Distance from Margin	Contact		616 mm (2.2 feet)		4,115 mm (13.5 feet)		7,600 mm (24.9 feet)	
	No. 1	Molecule	No. 3	Molecule	No. 6	Molecule	No. 8	Molecule
SiO_2	46.98	0.783	47.67	0.795	47.25	0.787	47.10	0.785
Al_2O_3	17.85	0.175	17.55	0.172	18.00	0.176	17.47	0.172
Fe_2O_3	3.13	0.019	2.51	0.016	2.21	0.014	2.66	0.017
FeO	10.30	0.143	12.59	0.175	12.42	0.172	12.93	0.179
MgO	(*a*) 7.10	0.177	5.65	0.141	6.35	0.159	6.88	0.172
CaO	(*a*) 8.47	0.152	10.75	0.192	11.45	0.204	10.27	0.183
Sodium oxide	2.04	0.033	2.21	0.035	1.96	0.031	1.91	0.031
Potassium oxide	0.60	0.006	0.65	0.007	0.66	0.007	0.59	0.006
H_2O at above 800° C	(*b*) 1.97	0.168	0.35	0.112	....	.....	....	.....
H_2O at 110° C	(*a*) 1.55	0.086	0.40	0.028	....	.....	....	.....
CO_2	0.20	0.005	0.18	0.004	....	.....	....	.....
P_2O_5	0.143	0.001	0.169	0.001	0.158	0.001	0.161	0.001
S	0.097	0.003	0.183	0.0057	0.086	0.0027	0.111	0.003
Cl	0.07	0.002	0.05	0.0014	0.02	0.0006	0.09	0.0025
MnO	0.26	0.003	0.19	0.003	0.18	0.003	0.15	0.002
	100.760		101.102		100.744		100.322	
Ratio, alkalis: SiO_2	0.048		0.053		0.0483		0.0472	
Ratio, pore space: solid space, in gasolene	0.0473		0.0012		0.0032		0.0018	
Sp. Gr. in gasolene	2.83		3.02		3.01		3.02	

(*a*) Checked later in another sample.
(*b*) Determined on new sample, first method incorrect.

labradorose as a limit up; and that those which occur with more than 30 per cent. of magma belonging to the femic eutectic are rare.

Moreover, it will be noted that there is among the orders between orders 4 and 5 a new principle of classification introduced. This corresponds approximately to the extra alkaline eutectics. Similarly, the rockallases appear very isolated and strange in the salfemic family.

I shall not, however, pretend to discuss the analcitic, melilitic, and other alkaline eutectic magmas, with which Iddings is much better acquainted than I. My object is rather to suggest that ultimately a more rational and natural, and therefore useful, classification of analyses might be attained if our main magmatic groups were defined by the eutectic within whose influence they come, so that in splitting one part will be nearer the eutectic and the other farther from it. I have Iddings's diagram to thank for this suggestion.

I am not going to say all that might be said about such intergrowths as perthite and sigterite (nepheline-albite), and other pegmatitic intergrowths as keys to eutectic proportions, because I do not wish to write a treatise, but rather a review—I fear too long—pointing out what seems to me inferences to be drawn from Iddings's diagrams. But the loss of mineralizers might change the eutectic. For instance, if the eutectic be $Na_2O \cdot Al_2O_3 + 6SiO_2 + 6H_2O \cdot SiO_2$, a loss of H_2O might mean the replacement of the H_2O by $\frac{1}{2}(CaO \cdot Al_2O_3)$ which might be a chemical quantitative change entirely worthy of recognition in a quantitative chemical classification, *if* it proved of sufficient importance; as much so as any magmatic split.

I think that the indications of Iddings's diagrams are that it is not from a quantitative chemical standpoint of primary importance, although his figures take no account of the water. It is not to be forgotton that in a holocrystalline rock the H_2O of the magma, while it may be in combination in biotite, analcite, etc., is very likely to be concentrated in drusic and microdrusic cavities, and not be noticed in the analyses at all, or, if at all, then in the water given off below 110°; but a maximum idea of this quantity may, however, be derived from the porosity, which in the dike mentioned above is for the more crystalline part less than a third of 1 per cent.

While, therefore, Iddings's diagrams do suggest a natural grouping and classification based on the various eutectics of various magmas, yet the time is not yet ripe for such a permanent arrangement. We do not know enough about the eutectics. In the meantime, the new system of pigeon holes has some advantages, and many, especially of the minor groups, may endure.

Still we can see that the old divisions of rocks might be grouped around the average rock and given a more precise chemical meaning, as follows:

1. Acid, *i. e.*, alkali-silica ratio 0.013 −, and silica percentage 0.58+, or limited as in diagram, eutectic ratio toward which crystallization takes place, alkali : SiO_2 : : 1 : 12.

Granites and diorites, and many syenites.

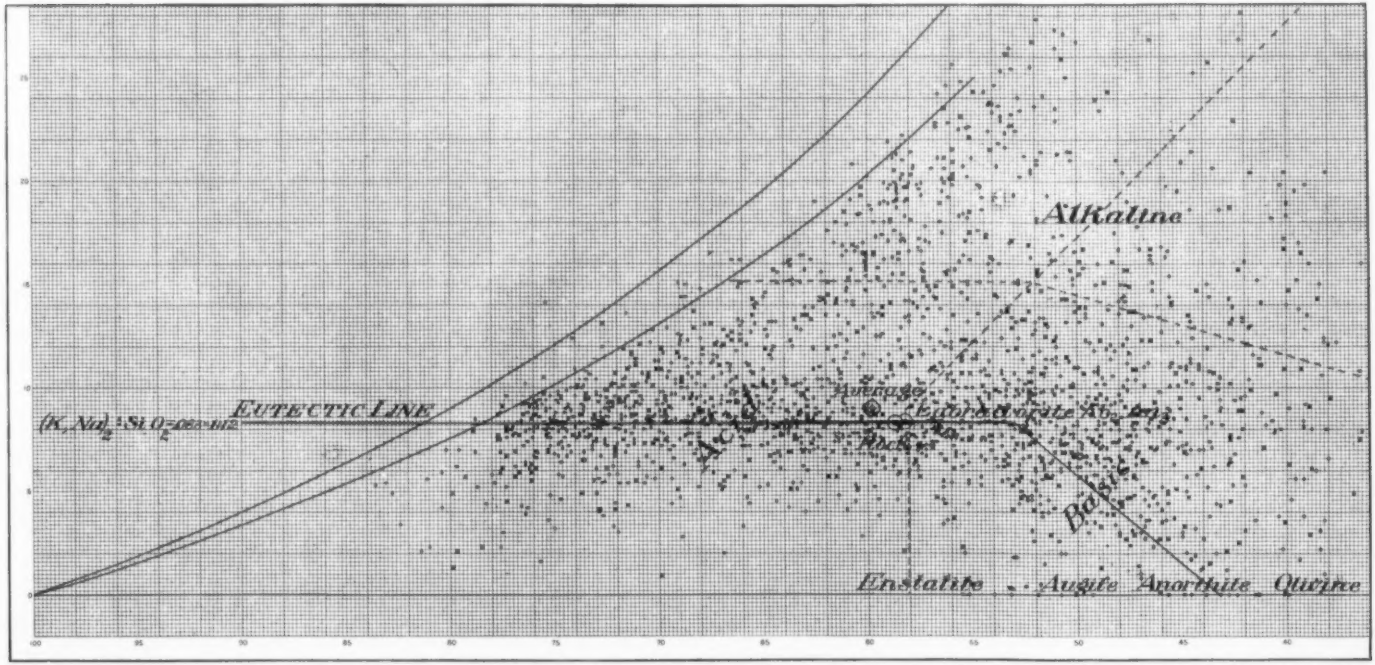

Diagram modified from Iddings's Plate I to show the natural clustering along the main eutectic line, and the possibility of a natural quantitative chemical classification of the igneous rocks.

The general rules for computing the norm of a rock can be simplified if made applicable only to this division.

2. Basic. Silica percentage, 0.58—, bounded, as shown on diagram perhaps, or by some other line expressing the fact that the eutectic is not melilite, but augite. Eutectic ratio, Ca : (Mg : Fe) : SiO_2 : : 1 : 1 : 2.

Basalts, gabbros, peridotites, etc. Computing the place of such rocks in a quantitative system is quite simple. All the alumina can be combined with potash, soda, and sufficient lime and counted salic, everything else femic, so that the ratio sal : fem is quickly found, and the ratio of soda to potash and alkalis to lime are found incidentally.

3. Alkaline. All other rocks, which obviously should also be subdivided, perhaps, as shown in the diagram, into a femic and salic group, and farther yet.

What ought to be done is carefully to study the whole field, with due regard to magmatic splitting, watching the last crystallization, and determine as nearly as may be what are the eutectic ratios in the silicate magmas. Then the work should be experimentally verified, in the new geological laboratory that I hope we are to have. Then, finally, we shall no longer have to envy the metallographist,[1] who measures the areas of micropegmatite (eutectic) copper and copper oxide, and areas of solid copper, and says: "So much eutectic with 3.45 per cent. Cu_2O, and so much plain copper: there must be just so much copper and so much oxygen."

In such study it is the last-formed minerals, with a little of nearly everything in their molecule, which show by their composition the eutectic proportions of the different constituents.

Since writing the above I have noticed in the *Beilage Band* XVII of the *Neues Jahrbuch*, p. 516, and especially pp. 546–64, an article by Schweig, and in the *Centralblatt*, 1903, p. 605, a note by Linck on a series of experiments exactly along the line

[1] HOFMAN, GREEN, AND YERXA, "A Laboratory Study of the Stages in the Refining of Copper," *Transactions of the American Institute of Mining Engineers*, October, 1903.

suggested, and in part only confirmatory of the suggestions above. For instance, Linck (pp. 606, 607) found a magma with 49.05 SiO_2 and an alkali silica ratio of 0.115, after absorbing all the silica it could at 1300° C. change to a magma with 52.20 SiO_2 and an alkali silica ratio of 0.082, almost precisely on the supposed eutectic line. Another with 62.62 per cent. silica absorbed a mixture of ferrous and ferric iron until the silica percentage dropped to 60.58 and the magma could be nearly expressed as $(NaK)_2O \cdot Al_2O_3 \cdot 6\ SiO_2 + \frac{1}{2}\ CaO \cdot Al_2O_3 \cdot 2\ SiO_3 + 3\ (Ca\ Mg, FeO)\ SiO_2$.

In Schweig's extensive series of experiments, starting with a strongly alkaline magma (17.5 per cent. alkali molecules), then adding separately silica, alumina, iron, magnesia, and lime to saturation, and then later adding also silica to saturation with the other oxide, only in case silica is added to saturation do we find analyses which are comparable with any of the rock analyses plotted by Iddings. The inference is suggested that the natural igneous magmas of the alkaline group are always able to absorb all the silica they will take.

When magnesia or iron oxide or alumina is added with the silica the alkali-silica ratio drops only to about 0.15. But the magma is much more capable of absorbing lime, and after saturation with lime and silica the alkali-silica ratio becomes 0.895 and the SiO_2 70 per cent., bring it well into the eutectic belt, which apparently therefore is that of magmas saturated with lime and silica.

All the glasses were cooled as quickly as possible, and no attempt was made to determine the temperatures of solidification. It would be interesting to repeat the experiments and note the latter.

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A FRACTURE VALLEY SYSTEM.

THE correspondence between the drainage system in the region north of the Yellowstone National Park and the system of fractures traversing the rocks is so striking that there can be little doubt of a causal relationship between them. The studies of de la Bèche in England, of d'Omalius and Daubrée in France, of Kjerulf and Brögger in Norway, and recently of Hobbs in Connecticut have demonstrated that in certain localities there is the closest correspondence between the valleys or drainage system and the fractures in the underlying rocks recognized as faults or joints. And Daubrée in his classic work *Études synthétiques de géologie expérimentale*, has shown how a more or less rectangular system of nearly parallel joints may be produced by torsional stress as well as by compression.

The almost universal application by geologists in former times of the idea of the controlling influence of fractures on drainage, and the exaggeration of the importance of faulting in this connection, coupled with the evident independence of many drainage courses from faulting, and their obvious dependence on other factors, led to a revulsion on the part of modern physiographers from the views of earlier geologists to such an extent that the influence of rock fractures on drainage courses has been minimized, if not altogether neglected, in recent times.

One reason for the revulsion from the idea of fracture drainage systems is to be found undoubtedly in the emphasis formerly laid on the conception of faulting as an essential element in the problem. This was introduced in the term "fault valleys," (*vallées de failles*) of d'Omalius, and has been memorialized in the vignette on the title-page of the *Annual Report of the United States Geological Survey*. That such valleys occur is well known, but that they form a small fraction of the whole is beyond dispute.

It is to be noted, however, that the demonstrations of Daubrée deal chiefly with joints or fractures (*cassures*), rather than with faults (*failles*), the two being but different phases of the same

phenomenon, fracturing; one, a result of small or imperceptible displacement; the other, of profound, or at least notable, dislocation. The torsional experiments of Daubrée produced more or less rectangular systems of nearly parallel fractures, some of which might be called joints, and others faults. The studies of Becker,[1] Van Hise,[2] and Hoskins[3] have established the laws and frequency of parallel and of conjugate joints (*systèmes conjugués* of Daubrée) and the phenomena have become familiar to all geologists who have worked in regions of well exposed disturbed rocks.

The phenomena are in part as follows: There are faults in more or less parallel lines through wide extents of territory intersected by faults at various angles often nearly 90°.

A dominant or major fault is frequently accompanied by parallel fractures of minor degree, which are in some cases close to the dominant fault, in other cases at considerable distances from it.

Faulting is accompanied in parts of its course by crushing and brecciation of the wall rocks; in other parts the sides of the fault are closely pressed together without evidences of brecciation. Further, there are portions of a fissure plane where the walls are not closely compressed, but may be actually open.

Planes of fracture and fissuring are often lines of special decomposition of the rock material, and are for this reason less resistant than the neighboring rocks.

From these facts it is evident that the course of drainage, in following lines of least resistance, may cut its way along fault lines where they are in brecciated, loosely aggregated, or decomposed rocks, but may leave the faults in places where unbroken rocks are closely compressed. Moreover, streams may find less obstacle in cutting unfractured softer rock than in removing fractured harder material.

[1] GEO. F. BECKER, *Monograph* III, *U. S. Geological Survey* (Washington 1882), pp. 156–87; *Bulletin of the Geological Society of America*, Vol. IV (1893), pp. 41–75; and *Transactions of the American Institute of Mining Engineers*, Vol. XXIV (1894), pp. 130–38.

[2] C. R. VAN HISE, *Sixteenth Annual Report, U. S. Geological Survey* (Washington, 1896), pp. 633–78.

[3] L. M. HOSKINS, *ibid.*, pp. 845–74.

Numerous parallel joints would aid erosion, if it were once located along a dominant fissure, by permitting the falling in of the sides of the drainage channels. Consequently, it is reasonable to expect that planes of fracture will in some cases become lines of drainage and pronounced erosion, while in other cases they may be disregarded by streams.

It is also known to every field worker that dislocations in large areas of massive rocks are easily overlooked, and are often difficult to determine when suspected; and further that minor fractures are generally neglected in geological field work. It follows from this that much evidence that may exist connecting the location of drainage with rock fractures has not been collected, and much that might be sought, by the very nature of the problem, may not be found, because the bottom of a valley is usually filled with loose material that conceals the rocks through which the valley has been cut.

A study of a mountainous region such as that lying north of the Yellowstone National Park must convince one that fracture systems have had more influence on the location of drainage than is ordinarily supposed, or than can be actually demonstrated, perhaps, by the evidence obtainable from the region in its present condition of rock exposure.

With regard to the presentation which follows, it is to be remarked that the problem of a possible fracture drainage system was not in mind when the writer was in the field, and no special search was made for evidence bearing on the question. The argument offered is based on such observations on the structure of the region as were made in the field by Mr. W. H. Weed and the writer, and on the drainage features of the map prepared by the topographers.

The topographic map which is reproduced is a reduction of that of the Livingston Quadrangle, Folio 1 of the *Geologic Atlas of the United States*. The geology of the district may be found in the folio. In this connection the map of the Three Forks Quadrangle Folio 24, and those of the Yellowstone National Park, Folio 30, should be studied.[1]

[1] U. S. Geological Survey, *Geologic Atlas of the United States*, Folio 1, Washington 1894; Folio 24 and Folio 30, 1896.

A simplified drainage map in which the drainage lines are somewhat straightened is given on the thin sheet, which is intended to be placed over the topographic map. The purpose of straightening the drainage lines is to present a simpler expression of the system, rendering the persistency of some of the directions more evident, and permitting the relationships of the various directions to be more easily noted. It does not follow that drainage channels would be more in accord with fracture systems if they were straighter. Fractures and faults are not necessarily straight. They are more often curved or crooked, as is the case with most of those observed in the region under discussion. The fault lines and dikes are printed in blue on the thin sheet. It is probable that the irregularities of direction in the drainage, as it is drawn on the topographic map, are more in accord with the fractures than the straightened lines traced on the drainage map. The value of the tracing is in the simpler expression of the system, serving the same purpose as a simplified statement of a highly complex set of relationships. It may be looked upon as a diagrammatic statement of the drainage system.

The region embraced by the map lies between the meridians 110° and 111°, and latitudes 45° and 46°. It is immediately north of the Yellowstone National Park, and contains the Snowy Range, the eastern slopes of the northern portion of the Gallatin Range, part of the Bridger Range, and the southern slopes of the Crazy Mountains. The Yellowstone River traverses the quadrangle from the south and southwest to the northeast, its tributaries intersecting the country in all directions.

A study of the topographic map reveals the angular character of much of the drainage system, and the prevalence of certain parallel and sub-parallel lines which appear in various streams and occur in quite diverse portions of their channels. Along parallel lines different streams may be flowing in opposite directions; one stream may be near its source, another near its mouth, having other portions of their channels trending in other directions. The persistency of these lines becomes more striking when the geological structure of the region is taken into account and it is observed that certain drainage lines traverse rocks of

such diverse nature as gneiss and schist, volcanic tuff breccia and solid lava, limestones, sandstones, and shales.

The relation of some of these directions of drainage to known fracture planes will be pointed out. The dominant drainage lines in the southern three-quarters of the quadrangle trend about northeast-southwest and northwest-southeast, more nearly N. 30° E. and W. 30° N., the angle between them being approximately 90°. There are other systems of almost rectangular lines somewhat differently oriented, namely, north-south and east-west. These are well developed in the central eastern part of the quadrangle.

Let us consider these systems in some detail, commencing with the main drainage channel, that of the Yellowstone River. This enters the quadrangle on the south in a curiously zigzag channel, known as the Third Canyon, cut in crystalline schists. The longer zigzag lines run northwest, and the shorter are almost at right angles. The northwest direction is followed from Gardiner to Reese Creek in Cretaceous strata, is exchanged for a more northerly direction as far as Yankee Jim, where the northwest direction is followed through a narrow gorge into the open valley, where a right-angled turn is made to the northeast. From Reese Creek to the open valley the river traverses crystalline schists.

The dominant northwest line of the river just described is parallel to the most profound fault within the region; namely, that which threw the whole sedimentary series, including the Laramie Coal Measures, down below horizons of crystalline schists. It is a fault of more than 11,000 feet and probably is more than 16,000 feet. This fault appears to end abruptly at Cinnabar Creek, the principal throw being southeast of Reese Creek.

It is interesting to observe that the Yellowstone River in no place exactly follows the fault line as it is located on the present surface. But it is evident from the topography of the country south of the river and east of Gardiner that parallel fractures must exist on both sides of the fault line, and these must control the northwest direction of the tributary streams and the longer

lines of the zigzag Third Canyon. These lines persist to the southeast within the boundary of the Yellowstone National Park, the fault itself being covered by younger volcanic lavas.

As already remarked, the great fault appears to end at Cinnabar Creek, but the Yellowstone River follows a line parallel to it through the gorge at Yankee Jim, and parallel lines of lesser drainage are plainly shown in the vicinity. Whether the fault actually ceases at Cinnabar Creek cannot be determined, because of the covering of volcanic rocks forming the surface of the mountainous country westward. Beyond these lavas, however, in a direct line a similarly profound fault is exposed in the Madison Range in the Three Forks Quadrangle. This was accompanied by a similar throw of the sedimentary strata south of the crystalline schists, and is in a direct line with the fault just described. The total length of the combined fault lines is over sixty miles.

Parallel to this great fault are several well defined ones of less extent, the largest lying north of Mill Creek Basin. Here there are two sub-parallel faults which unite in the head of the North Fork of Mill Creek. The dominant one of these has been traced from the Boulder Canyon westward to the Yellowstone Valley, a distance of twenty miles. The shorter fault has been traced for thirteen miles. They are not observed west of the Yellowstone Valley in the Gallatin Mountains because of the covering of volcanic lavas, but they appear again with the same characters in the Madison Range just west of the lavas, evidently passing beneath them. The western faults are exposed for twenty miles, and there can be no doubt of their persistence beneath the lavas. In this case the total length of the principal fault would be sixty-four miles.

In the bare gneisses two miles north of the fault line at the head of the North Fork of Mill Creek joint planes or small faults are clearly visible, parallel to the main fault and having a hade to the south, indicating normal faulting.

In other parts of the region there are faults parallel to those just described. A small one within the area of crystalline schists occurs in the southeast corner of the quadrangle, crossing

Slough Creek. It is exposed for a short distance only, being covered at both ends by volcanic rocks. A still smaller one was observed six miles farther north. These indicate the presence of fractures parallel to the profounder faults.

North of the body of crystalline schists a northwest fault exists in the valley of the East Boulder River; another is situated south of Livingston Peak; and two smaller faults occur between this mountain and Livingston. Two more are located just west of the Yellowstone River in this vicinity; and there is a short one northwest of Mount Ellis, in the central western margin of the quadrangle.

The presence of major fractures in a northwest-southeast direction being clearly established, the occurrence of parallel fractures of minor importance is rendered highly probable, some in fact, having been observed in the field.

Corresponding to these northwest-southeast fractures are the channels of many of the tributaries of Slough Creek, Buffalo Creek, and Hell Roaring Creek; the minor branches and the main channels of many of the streams flowing into the Yellowstone, as far as Livingston, notably those in the Gallatin Range. The most remarkable instance, which is a good example of a fault valley, is the valley of East Boulder River.

Returning to the consideration of the course of the Yellowstone River, it is seen that upon leaving Yankee Jim Canyon it flows at right angles through a broad valley in a northeasterly direction for forty miles. More strictly, the first twenty miles are about N. 30° E., the next sixteen miles being more northerly. From the mouth of Shields River beyond Livingston the course is south of east, nearly at right angles to its course at Livingston. This is followed by a right-angled bend at McAdows Canyon, after which the course is northeast to the edge of the quadrangle.

The broad valley of the Yellowstone between Yankee Jim Canyon and the Lower Canyon, which valley continues southwest up Tom Minor Creek, lies in the direction of a scarp fault forming the western flank of the Snowy Mountains. The summits of gneiss and schist at 11,000 and 10,000 feet from Emigrant

Peak to Mount Delano rise abruptly on the east side of the valley, while on the west there are the long sloping spurs of volcanic lavas overlying sedimentary strata in the northern part of the Gallatin Range. The location of this fault was not discovered in the field, as it is undoubtedly obscured by the valley deposits. It dies out abruptly before reaching the Lower Canyon, near Livingston, and is probably most profound north of the cross fault at Mill Creek.

This northeast direction is the same as that of two pronounced faults in the southwest corner of the quadrangle that enter it from the Yellowstone National Park. One lies in the drainage channel of Cinnabar Creek; the other is in the valley of Reese Creek. It is probable that a third fault parallel to these occurs in the valley of Gardiner River west of Mount Everts, but it has not been definitely located. These faults terminate in the great northwest fault in Yellowstone Valley south of Sheep Mountain.

The throw of the Cinnabar Creek fault is to the west, but the extent of the displacement is not determinable. It has been traced for a distance of eighteen miles. The Reese Creek fault is clearly recognizable east of Electric Peak, where the throw is to the east and the displacement more than 6,000 feet. It continues southward as a scarp fault along the east flank of the Gallatin Mountains in the Yellowstone Park. It is known for twenty miles, and disappears under lava. The throw of the fault west of Mount Everts is to the west.

A minor fault parallel to those just described occurs in the gneiss east of, and parallel to the channel of Hell Roaring Creek. Several northeast-southwest faults of slight extent have been noted north of the great body of crystalline schists. One is a short spur connected with the fault in the valley of the East Boulder River. Two are connected with the northwest-southeast faults southeast of Livingston, and another is south of Mount Ellis in the western part of the quadrangle. In each of these cases it is interesting to observe that there are conjugate faults at nearly right angles.

In the direction of the northeast-southwest fractures, besides the Yellowstone Valley and Cinnabar and Reese Creeks, which

are definitely located on fault lines, there are the channels of Bear Gulch and Crevice Gulch, Hell Roaring and Slough Creeks, with tributaries to Boulder River and Mill Creek, and the upper portion of the West Boulder.

Another conjugate system of fractures is indicated by the rectangular drainage with lines almost north-south and east-west. The direction of the main Boulder River through its canyon is the same as that of several of its head branches, of Buffalo Creek to the south, and of several north-south drainages to the east. The east-west direction is found in tributaries of the Boulder River, in the North Fork of Mill Creek, and in a stream in line with this east of East Boulder plateau. In this case there is a fault nearly parallel to the North Fork of Mill Creek connected with the northwest-southeast system of faults. An east-west fault has also been observed by Mr. W. H. Emmons near Haystack Peak at the head of Boulder River. There can be little doubt that in this portion of the quadrangle there is a system of fractures in an east-west and north-south direction.

The sculpturing of the canyons of the Boulder and West Boulder, and of several to the east, seems to require the action of other agencies than those of ordinary erosion. These narrow canyons have been cut 3,000, 4,000, and 5,000 feet into gneiss and schist within a few miles of their heads, and their drainage basins seem quite inadequate to furnish sufficient water for so great and such deep erosion. It seems as though the rocks must have been rendered more susceptible to abrasion by being fractured or jointed.

A similarly placed system of drainage channels exists in the northwestern corner of the quadrangle west of Shields River and east and south of the Bridger Range, but no system of fractures or faults has been noted in this region.

The northeastern corner of the quadrangle is intersected by a distinctly rectangular system of drainage. The channels of the Yellowstone and Boulder Rivers, with the tributaries of the Shields River, have a northern trend nearly at right angles to those of Shields River and several creeks flowing southeast from the Crazy Mountains, and numerous small tributaries of the

Yellowstone and the Boulder Rivers. That these directions are parallel to existing fractures is shown by the trend of dikes of igneous rock that traverse this part of the country. A number of dikes occur in Crow Indian Reservation on the Boulder River. They trend northwest almost exactly parallel to the small streams in this vicinity. Two longer dikes occur on Gage Creek, trending in the same direction. In the valley of Shields River there are dikes having a northeast-southwest trend. The Crazy Mountains are filled with innumerable dikes radiating in all directions from the core of igneous rocks lying north of the Livingston quadrangle. That portion of the mountains within the limits of the map is traversed by dikes trending north-south in the middle of the group, on the east side trending east of south, and on the west side trending west of south, but not parallel to the drainage channels in the foothills. Apparently these fractures are immediately connected with the intrusive core of the mountains, and have not extended into the surrounding sedimentary strata for long distances. The system of fractures indicated by the drainage is probably more profound and was produced by deeper-seated forces.

There are dikes and lines of intrusive rocks parallel to neighboring drainage channels in the vicinity of Haystack Peak, Emigrant Peak, and at the west base of Sheep Mountain.

Besides the drainage that may have been controlled or initiated by fracture lines, there are within the area covered by the map excellent examples of channels that have followed softer rocks, where the minor topographic features of the country conform to the position and character of the sedimentary strata, and where fracture and faulting appear to have had no influence on the drainage. It is the larger valleys and dominant channels that exhibit the general relationship between drainage and fracture.

That the drainage system of this quadrangle is closely related to the structural features of the rock formations will not appear surprising when the geological history of the region since Laramie times is taken into account.

The dislocation of the crystalline schists and sedimentary strata that followed the deposition of the Laramie resulted from

torsional shearing stresses of great magnitude, as is shown by the rapid variation in the amount of displacement along the planes of faulting. These fractures have occurred in nearly parallel planes, and also in a nearly rectangular system, and resulted in faults and joints.

The fractured and dislocated rocks were eroded to a very great extent at a very early period. Thus from a large area the entire sedimentary covering, 10,000 feet or more in thickness, was removed from the underlying crystalline schist before Eocene times, and the surface of the country presented an irregular topography not greatly different in character from that of the present day. Upon an irregular surface of crystalline schists in the present valley of the Yellowstone River, just south of the Livingston quadrangle, there rest horizontal beds of Eocene volcanic tuff with ancient tree trunks in vertical position. Erosion has reduced the rocks in this vicinity to nearly the same surface at successive periods, as is shown by the occurrence of surface extrusive lavas of very different ages in close proximity. The direction of the drainage in this locality has undoubtedly shifted repeatedly during this long lapse of time.

Since volcanic activity commenced, fracturing and faulting have taken place at intervals through the Tertiary period. The profoundest faulting and erosion took place before Eocene times and the extravasation of Eocene tuffs. This was followed by great accumulations of Miocene tuffs and lavas, which were fractured and dislocated along the faults in Cinnabar and Reese Creeks, and elsewhere. These were greatly eroded in late Tertiary time before the eruptions of Pliocene rhyolite which has been faulted in its time.

In the faulting of the Electric Peak and Sepulchre Mountain blocks there was unquestionably a displacement along the line of the earliest northwest-southeast fault against which these blocks terminate proving a recurrence of fracturing and displacement along old lines of jointing and faulting. And while there is little or no evidence in this region that successive faulting has often taken place at widely remote geological periods along the same lines, it seems probable that profound jointing may establish

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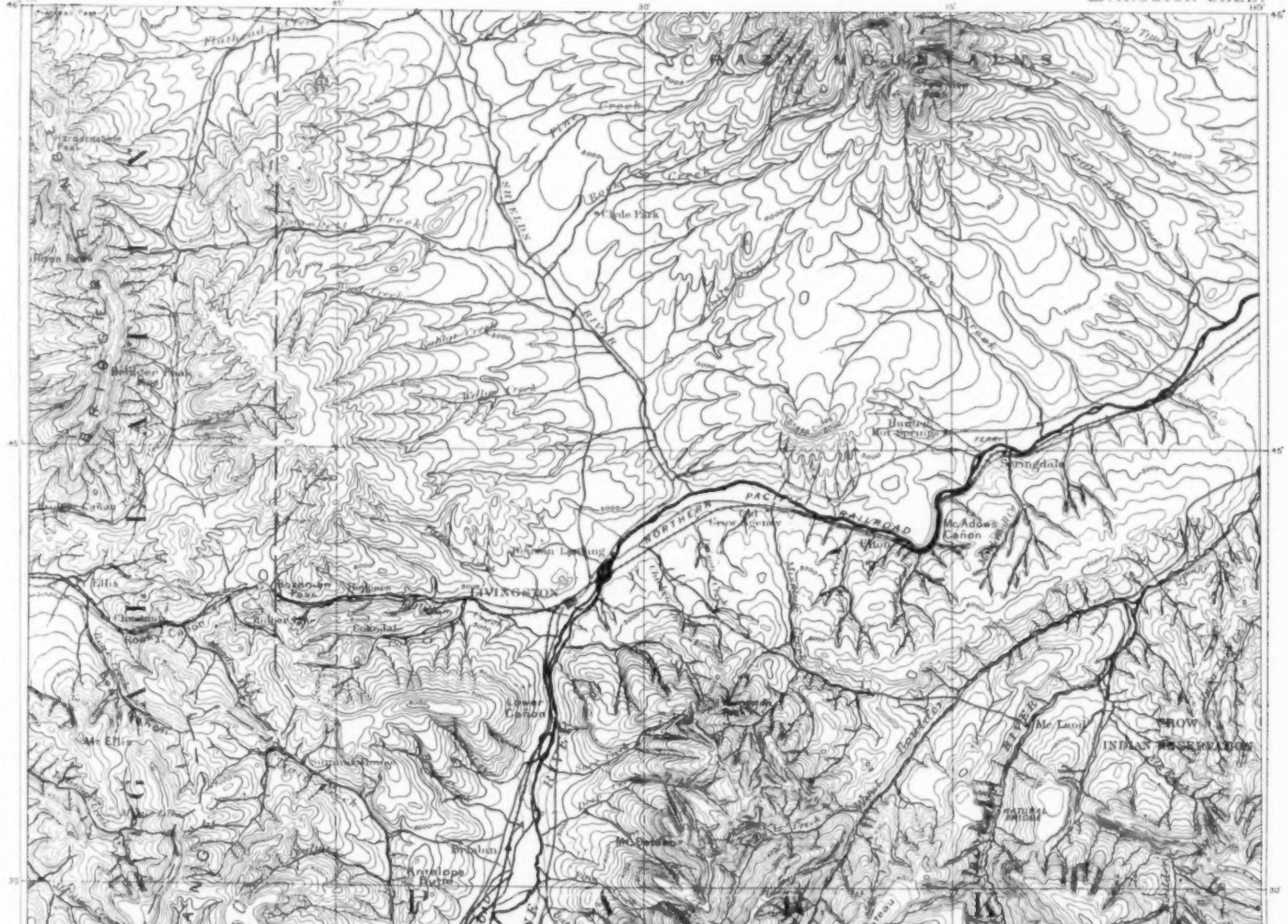
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Bridger Range
Baldy Mtn.
Hyalite Peak
Hyalite Creek
Bozeman Pass
Bozeman
Bridger Canyon
Middle Creek
Bull Creek
Dry Creek
Bear Canyon
Sourdough Creek
Sourdough Canyon
Bozeman Tunnel
Mt. Ellis
Ellis
Gallatin River
Gallatin Canyon
Gallatin Range
Lyle Park
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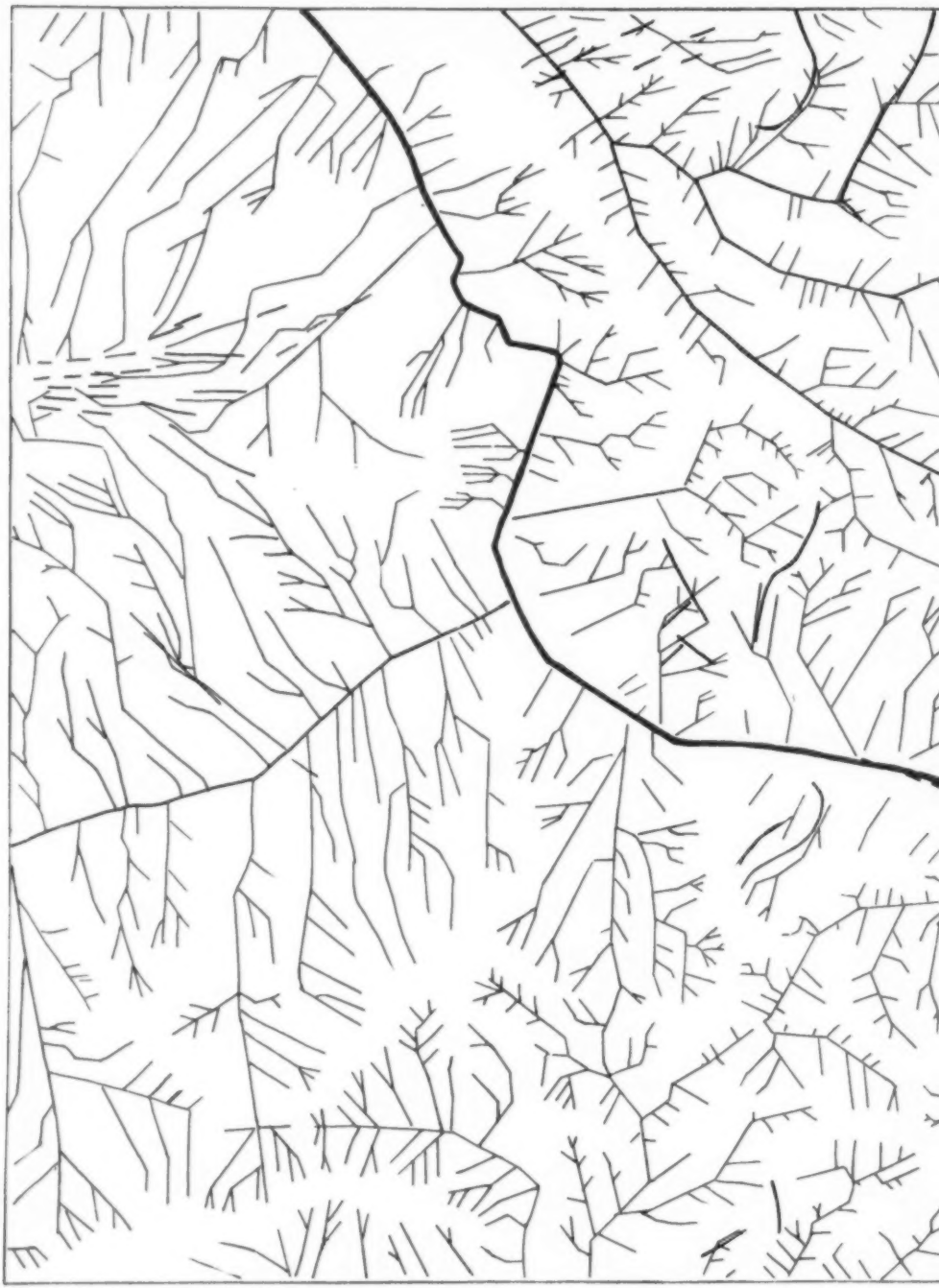
Antelope Butte
Pinyon
Pacific Railroad
Yellowstone
Livingston
Pinedale
Northern Pacific Railroad
Big Timber
Grand
Duck Lake
Dailey
Dome Mt.
Mill Creek Basin
Mill Creek Mts.
Mt. Douglas
Mt. Wood
Mt. Maddock
Mt. Rose
Mt. Rose
Mt. Rose



planes of weakness along which subsequent movements of a minor character may take place affecting superimposed rocks, so that a system of Eocene, or even late Cretaceous, joints may be extended upward into overlying rocks in Miocene time provided similar dynamic action of a pronounced character occurs in both periods as it has in this region.

JOSEPH P. IDDINGS.

CUSPATE FORELANDS ALONG THE BAY OF QUINTE.

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INTRODUCTION—THE BAY OF QUINTE.

THE flat-lying limestone regions immediately to the north and east of the east end of Lake Ontario are traversed by a number of deep valleys with graded side slopes on their lower courses. These valleys are probably of preglacial origin, and were carved at a time when the relative altitude of the several parts of the Ontario lowland was different from what it is at present. The partial submergence of a number of these valleys, tributary to one another, has formed the water body known as the Bay of Quinte. This bay extends from near Kingston, at the east end of Lake Ontario, toward the southwest for a distance of over fifty miles, and nowhere has it a breadth exceeding two miles. A reference to the accompanying general map will show its remarkable zigzag course.[1] For purposes of study it may be

[1] For a discussion as to the probable origin of this valley see "The Trent River System and the St. Lawrence Outlet," *Bulletin of the Geological Society of America*, Vol. XV.

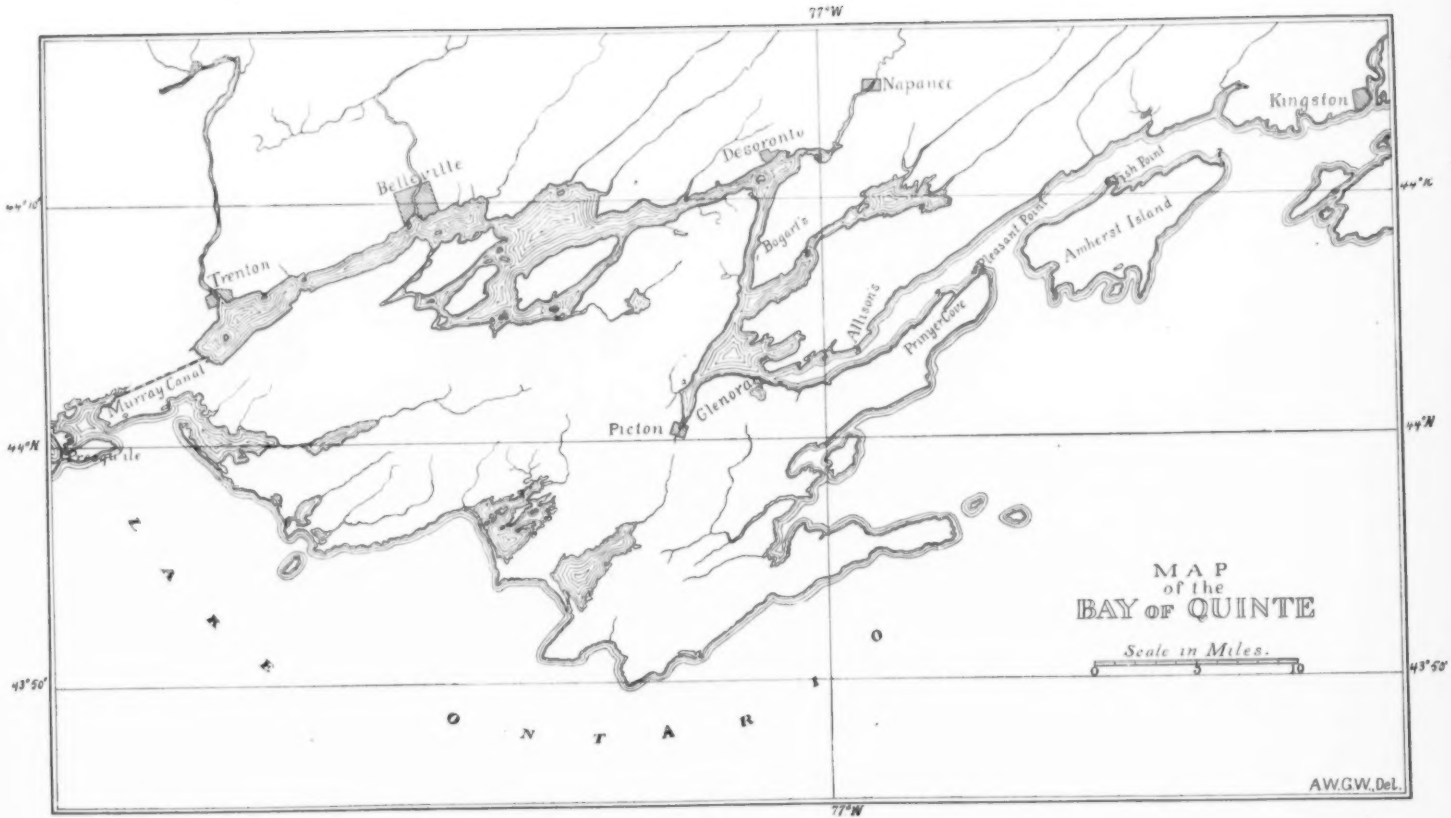
77°W
Napanee
Kingston
Deseronto
Belleville
Trenton
Bogart's
High Point
Pleasant Point
Amherst Island
Allison's
Prinyer Cove
Murray Canal
Picton
Glenora
44°N
43°50'
MAP
of the
BAY OF QUINTE
Scale in Miles.
0 5 10
ONTARIO
A.W.G.W. Del.
77°W

FIG. 1.

divided into three parts: the Trenton-Desoronto section, trending a little north of east; the Desoronto-Picton section, trending to the west of south; and the Picton-Kingston section, trending nearly northeast.

The upper section is comparatively shallow; for the most part the shores are rocky; and no characteristic cuspate forelands have been noted along them.

The middle section, sometimes known as the Nine Mile Reach, has much deeper water, and the valley sides are steep, often inaccessible cliffs of Trenton limestone. The maximum relief is about 185 feet. Much of the shore is rocky, but along the east side there are, in places, small amounts of modified drift lying between the water's edge and the front of the adjacent escarpment. In one place, a short distance below Bogart's dock, shore drift derived from this material has formed a small foreland of fine sand which resembles the V terrace with the rimming bars which Gilbert describes as occurring on the shores of Lake Bonneville. On the west side of Picton Bay there are also two small spurs of shore drift which seem to be associated with talus cones from the face of the cliff.

Along the third section of the bay there are four excellent examples of the cuspate foreland and one long flying spit. Some of these cuspate forelands have a remarkably close resemblance to the V terraces and V bars of Lake Bonneville. Parts of the shores of this section of the bay are also rocky, but the amount of drift, both till and stratified material, is greater than elsewhere. Off the west end of Amherst Island the water has its maximum depth of 230 feet. The valley reaches its maximum relief of 284 feet near Glenora. The south shore is bordered by the steep escarpment of a cuesta which rises about 200 feet above water level near Glenora. The height gradually decreases eastward, and in Amherst Island it is only about 50 feet. The north shore rises gently inland. On the south shore rock exposures are numerous; on the north shore glacial drift frequently occurs, bed-rock less often. Of the four cuspate forelands to be described, three occur on the south shore; the flying spit is located at the extreme eastern end of Amherst Island, also on the south side of the bay.

The material which forms the loose débris of the shore is in part derived from the wasting of the cliffs, in part from the glacial deposits. The material which forms the single spit which occurs on the east side of the middle section, and also that of the spit which occurs on the north side of the eastern section of the bay, seem to be wholly of glacial origin. The materials of the three forelands and the flying spit which occur along the south side of the eastern section of the bay are largely derived from the bed-rock where it outcrops along the shore, but there is a slight admixture of gravels derived from the glacial deposits.

MOVEMENTS OF THE WATERS OF THE BAY OF QUINTE.

Currents.—Before describing each of the spits in detail, and discussing the question of their origin, it is considered advisable to say a word about the movements of the waters of the bay. As is well known, there are no appreciable tides on the Great Lakes; hence tidal currents do not enter as a factor in the distribution of shore waste. The volume of water discharged by tributary streams into the upper part of this bay is considerable, but its ratio to the total amount of water in the bay is so small that no appreciable outflowing currents are set up. It is altogether doubtful that any portion of the bay water below Desoronto has a normal current from this cause of over a mile per day.

The seiches of Lake Ontario periodically affect the height of the water of Kingston. Accurate data are not at hand to permit of any statement of their exact periodicity, but by calculation it should be about sixteen hours between wave-crests. The change at Kingston ordinarily does not exceed a foot and a half, except during and after exceptional storms, when it is much greater. The water that is backed into the bay at the time the crest of the seiche-wave is at Kingston must theoretically cause an oscillatory movement in the bay, as the crest and trough of the seiche-wave travel up the bay. At Napanee, at the head of the navigable portion of the Napanee River, about seven miles above Desoronto, this seiche-wave often makes a difference in water level of about 3 feet. Here, however, the water is backed

into a narrow funnel-shaped opening. Out on the open bay very slight changes in level are occasionally noticeable, but no records of their amounts are available. It may, however, be stated that they are very slight, and at no time, except at the upper part of the Napanee estuary has the writer been able to determine the existence of any noticeable current due to this cause. It may be stated that the currents in the bay produced by this cause are not capable themselves of transporting any of the material which is moved along the bay shore. It is true that they may slightly accelerate or retard the currents which are concerned in the active transportation, but they are much too weak to be in any way considered as active and effective agents in transportation. Where they have been observed at their maximum the water is perfectly clear, although the bottom is covered with a fine mud which settles rapidly when stirred.

Approximate estimates as to the strength and importance of the seiche currents can also be made at the Murray Canal. This canal is four miles in length and connects the upper end of the bay with Presqu'Isle Bay, this latter bay connecting directly with the open lake. The crest of the seiche reaches Presqu'-Isle Bay some hours before it reaches Kingston. Consequent on the rising of the waters at Presqu'Isle Bay a current sets in eastward through the canal to the head of the Bay of Quinte. Some hours later the crest of the wave advancing from the Kingston end of the bay, having had about 110 miles farther to travel, reaches the head of the bay, and occasionally may start a current through the canal in the opposite direction. Unfortunately, it has not been possible to carry on simultaneous observations at several points on the bay, nor at any one point continuously for a long enough period to establish the time relations of these oscillations. The existence of the currents through the canal has been established. These currents in the canal are farther complicated by wind-action which generates surface currents. From observations made during periods of calm weather the author would infer that the current to be attributed to the seiche alone rarely exceeds five miles per day. It must be noted that until careful quantitative observations are made there can be

no definite statement, for even during calm weather the momentum of wind-generated currents causes them to continue for a considerable period, and it is difficult to distinguish positively between these residual currents and the true seiche current.

In the absence of accurate observations of the time of oscillation of the seiche, we have no means of knowing whether the crest of one wave starts the currents through the canal from one direction at the time when the trough of another is at the opposite end of the canal; in other words, we do not know whether the current periodically reaches its greatest possible maximum value. Assuming a mean depth in Lake Ontario of 65 feet, and making some allowance for retardation of the advance of the wave-crest up the narrow bay, a calculation of the time of oscillation of the seiche along the line of direction of the most prevalent storms suggests that the periodicity of coincidence of crest and hollow at opposite ends of the canal will not be the same as the period of the seiche.

The mean depth of the canal is 11 feet; the breadth at the bottom, 80 feet; the breadth of the water surface, 125 feet. It may be inferred from the small volume of water moved through the canal by the seiche current that in the much broader, deeper bay the actual currents generated by the seiche oscillation must be very slight.

Waves.—The effective agents in the transportation of the shore débris are wind-waves, and the longshore currents which are associated with them. The size of the material transported and the rate at which it travels must necessarily depend upon the strength of the waves; these in turn depend upon wind velocity, and, in the Bay of Quinte, upon wind direction. Observations which have extended over a considerable period have shown that resultant effective transportation along the shores of the Great Lakes depends in part upon the direction of the most prevalent winds, in part upon the length of the stretch of open water across which the acting wind has come. The larger storms usually determine the resultant direction of transportation. Now, in the case of the Bay of Quinte, the steep sides of the valley in which the waters of the bay lie so guides and controls the winds

that we find that the efficient wave and wave-current work in shore transportation is done by those winds whose direction conforms nearly with the axial direction of the several sections of the bay. The narrowness of the bay, coupled with the depth of the valley, is such that even violent storms blowing across it can do less efficient work than is done by the much gentler local breezes blowing up or down the bay.

In this locality the prevailing direction of the wind during the summer is from the southwest; but, in spite of this, it is found that, because of the considerations to be noted below, there is virtually no continuous transportation eastward except along parts of the lower portion below the Upper Gap. There seems rather to be a constant oscillation to and fro. Because of the shape of the bay and its position the directions from which efficient winds and their accompanying waves can come are the northeast and the southwest.

The material which forms the forelands varies from fine sand in one example to large rock plates weighing over four pounds each. All the spits but one are built of coarse and fine gravel or shingle. In most cases the material is almost all so coarse that its transportation must be attributed to the wave itself, rather than to the action of any longshore current during the intervals that the wave may have raised it off the bottom, though no doubt these currents assist in that transportation to a small extent. It is moved in part by rolling along the bottom, but even some of the largest fragments are frequently lifted clear of the bottom and carried along with the wave. The shape of the oblong or rhomboidal plates (rarely over an inch thick, and with an area on the flat side, varying from ten to thirty square inches) materially facilitates this mode of transportation.

THE FORELANDS AND BARS.

1. *Sand spit below Bogart's dock.*—This is a small spit which consists wholly of fine sands derived from the adjacent cliff cut in modified drift. The spit measures about 245 feet across the base and extends about 100 feet out from the shore line. The normal width of the beach between the cliff front and the water

is about ten feet. In its present attitude the axis of the spit inclines toward the southwest or slightly down the bay. A reference to the accompanying sketch plan will show the present existing conditions. There is a central triangular terrace at water level, marshy, but filling with sand which drifts in or is washed in by rains or waves. Bordering this are two distinct sand ridges rising about 2 feet above water-level. The outer ridge has imponded a small amount of water between itself and the inner ridge. A third ridge has been begun on the outside of these two.

Referring to the general map, it will be seen that effective

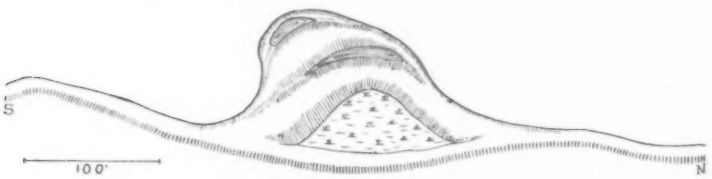

FIG. 2.—Small sand spit below Bogart's dock, June 1, 1903.

transportation must always be by winds blowing nearly parallel to the axis of the middle section of the bay. The present shore line, both above and below, is certainly just as irregular as it is here—it would be described as slightly wavy. There is no stream discharging near here, and there is no evidence of a local landslip having modified the shore line in such a way as to cause the beginning of the building of the spit at this point. In the field it was at first very difficult to see in this case why it should have happened to be formed here and not at a half-dozen other apparently similar places. It happens, however, that there is a very slight, though noticeable, difference in the curvature of the shore line at this place, and it seems as if, under certain special conditions of wind-action from the east of north, the longshore wave and wave currents first started to build a terrace and later a bar outward from the slight salient in the shore line of this point, and that the *same* waves gradually turned the end of this free bar as it reached deeper water, giving it its curved form, and finally tying it on to the shore again. This bar was subsequently

modified and its curves readjusted by waves coming up the bay. At a later period the second bar was built outside the first, under a similar succession of conditions, the waves most actively concerned in its construction coming from the southwest. The third portion was in part built during the summer of 1903, under the action of a series of storms from the northeast. During the process of its building the waves cut into the earlier bars on the north side, producing the concave curve in the shore line at this point, and depositing the eroded material nearer the apex of the spit on the far side of the axis of the initial form, producing the asymmetrical form shown in the plan. If their action continued long enough under the conditions existing at the time the observations were made, the bars would be extended in a very much larger loop and would inclose a very much larger lagoon. The rounding of the end of the spit and the shaping of the convex and concave curves on the south side were actually done by the same set of waves which brought the material to form the outer cap of the spit. In this, as in several other cases, even where the material was coarse gravel, the apex of the spit lies so far off-shore that waves curving obliquely toward it from either direction will only have their shoreward ends retarded as they advance obliquely on the shore. The off-shore portions advance in the deeper water virtually unretarded, and thus the wave front is rapidly curved around the end of the spit. Material moved along a side of the spit toward the end, when discharged at the apex, will often be carried around the end by the more vigorous unretarded portion of the same or the next following wave to that which accomplished its final discharge at the point.

This sand spit seems to be rather an evanescent than a permanent feature of the shore. The present spit is, from the character and size of the sedges growing in the lagoon area, inferred to be several years old, probably not more than five.

2. *Grand bars on Picton Bay.*—On the west side of Picton Bay, nearly opposite the west end of the third section of the Bay of Quinte, are two peculiar bars forming two distinct loops, convex outward, joining the shore by two short concave curves of adjust-

ment. The beach between the cliff-foot and the water is here quite narrow, usually less than 6 feet in width. Above and below the two-loop bars in question the shore line is slightly sinuous, but the beach is of very uniform width. Between the two bars there is a stretch of 78 feet where there is not enough beach gravel to cover the bed-rock, and the cliff rises directly from the

FIG. 3.

water, here about a foot in depth at the shore line. The south loop is 220 feet in length, and the north one 280 feet. The north loop holds a long, narrow little pond between it and the old shore. The low area between the south bar and the old shore was above present water level, and was nearly filled with gravel.

The sudden departure from the normal conditions along this shore to form these bars is difficult of explanation. In the pres-

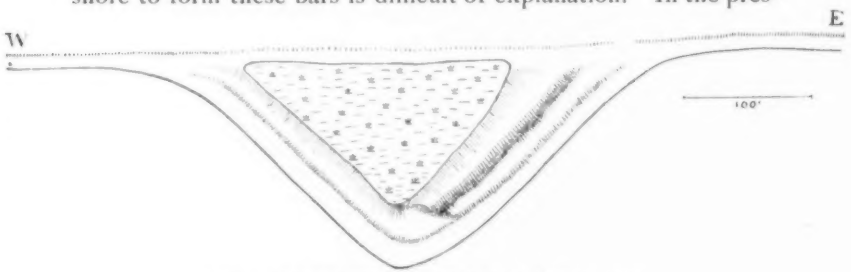

FIG. 4.—Foreland near Allison's dock, May 22, 1903.

ent instance it is possible that a small landslip from the cliff may have temporarily changed the shore line in such a way as to necessitate readjustment by the waves. On the other hand, they may have been formed under the action of the waves alone on the normal shore line, under conditions referred to below in a general discussion of the origin of the forms here described. In this latter case they represent initial stages of a form which reaches its perfection in the V terrace and V bar.

3. *Terrace and bar near Allison's wharf.*—On the north shore of the eastern section of the bay at Allison's dock, there is a sea-

cliff 25 feet in height, cut in till. To the east the cliff becomes much lower. About half a mile east of the wharf occurs one of the most perfect examples of the V-bars. The sea-cliff of till here has a height a little under 5 feet. There is a narrow beach about 20 feet in width. The front of the cliff behind the foreland is more subdued than elsewhere; it is graded, and is covered with sod. The bars which inclose a triangular lagoon are built of gravel and sand. The material of the east arm is chiefly a coarse gravel; that of the west is gravel with a much larger percentage of finer material and some sand. On the inner side there is a small amount of clayey soil which has gradually been blown or washed into the lagoon. The bars are of at least three periods of formation. The oldest rises 3.2 feet above water level the next oldest 4 feet, and the present one about 3 feet. The older beaches have been in part cut off by the newer, as shown in the plan.

The inclosed lagoon is triangular in outline, with rounded corners. The base on the old shore measures about 210 feet, the apical distance along the axis is about 135 feet. The depth of water is about 18 inches. It is more or less grown over with water plants and grasses. The east arm of the triangle measures 144 feet; the west, 165. The apex of the spit is rounded and the nearly straight sides join the shores with short concave curves of adjustment. The east arm of the bar is much higher and wider than the west arm, and its outer end has several times been truncated by stronger storms from the east. The present form of the spit is thought to be due to the activity of the waves, chiefly from the east. The western arm has been straightened and smoothed off at frequent intervals by the less violent, but more constant waves from the southwest. The bottom on which the terrace rests here slopes rapidly downward under the bay, the 100-foot contour lying less than a quarter of a mile off shore.

A reference to the general map shows that this spit is located very near one of the most salient points of the north shore of this section of the bay. On the ground its actual location is about a quarter of a mile to the east of this point, and hence it is sheltered by the point from the storms which blow directly

down the bay from the southwest. Waves which travel up the bay from the east would apparently have their maximum effect on the beach at this point. A little farther east there is another minor point, too small to show on the plan. Beyond this toward the large point (a drumlin) shown on the plan, about a mile and a quarter east of Allison's wharf, the shore débris is very much coarser. Both to the west and east the rawness of the shore cliffs and the coarser beach débris show that there is much more active erosion going on there than in the immediate vicinity of the

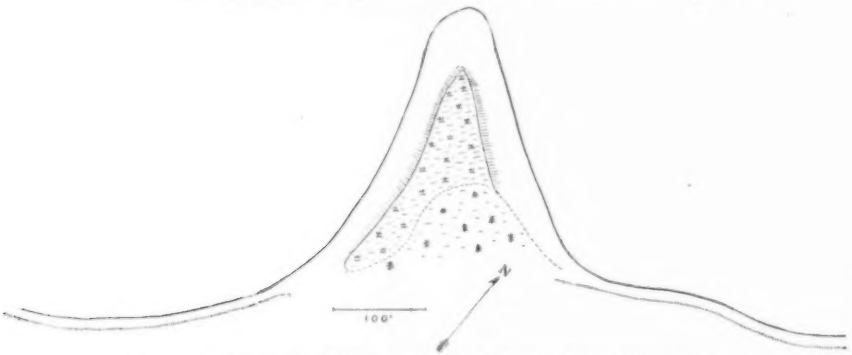

FIG. 5.—Foreland about half a mile west of Prinyer Cove, June 1, 1903.

spit. The inference there seems to be that just at this locality we have a region of relatively quiet water and less activity, where material eroded by the waves acting alternately at different intervals tends to accumulate.

4. *Prinyer Cove spit.*—About a mile west of Prinyer Cove there is a slight salient on the shore line which is tipped by a small V terrace and rimming bars inclosing a triangular lagoon. The axis of the spit lies nearly at right angles to the trend of the shore line. The spit is 275 feet in length and measures about 300 feet across the base. The sides are nearly symmetrical, and the inclosing bars are built of gravel. The inclosed lagoon is in part filled up with rank marsh vegetation; near the edges are some large trees. The apex of the spit shows the lines of successive additions on alternate sides. Inside the present beach only one of the earlier beaches is well preserved. This has been in part

cut into during the readjustment of curves when the present beach was built. The land behind the shore is overlaid by a thin sheet of till. It slopes gently bayward, and the inner margin of the lagoon gradually merges into the mainland. Both on the east and west there is a low cliff above the beach having a height of about 2 feet. The cliff and beach that must have existed behind the lagoon have long since disappeared. The gravel bars on the sides rise about 3 feet above water level. That on the east is a little larger, and consists of coarser material than the one on the west. Almost all the gravel composing the bars is derived from the adjacent bed-rock—a nodular shaly limestone of Trenton age.

5. *Pleasant Point spit.*—This is the largest and the most interesting of all the forelands on the bay. The general form of the foreland is shown by the accompanying plan. The material of which it is built is almost wholly gravel. The eastern side consists of very coarse shingle containing numerous flat plates of all sizes up to three or four pounds in weight. The west arm, on the other hand, consists chiefly of smaller rounded pebbles, rarely over an inch in diameter, and there is also a certain amount of fine gravel and sand.

To the west of the foreland there is a shore cliff about 20 feet in height, of which at least the upper 5 feet are glacial till. The base of the cliff is shaly limestone, and the width of the normal beach is between 6 and 10 feet. It is strewn with coarse cobbles, there being very little fine material such as is found on the arm of the spit a few yards away. The old cliff runs behind the spit; twice it changes its direction, recording significant changes in the growth of the spit. Its height at the base of the eastern arm is only about 5 feet. It continues as a low bluff for some distance to the southeast. The drift varies in thickness, but near the spit its thickness is about 2 feet.

The original foreland so far as it can be traced, lay a little farther to the west than the present one, and was very similar in shape and size to that near Prinyer Cove. At the present time there are seven distinct beaches. Counting east from the inner triangular lagoon, the first three of the beach mounds or ridges each

rise only about a foot above present water level. They are nearly parallel, and between them we find two long, narrow ponds. The fourth beach, the largest and highest of the series, extends nearly the whole length of the spit. The next two are also of considerable height and breadth, and are best preserved near the outer end. In the readjustment of the curves during the formation of

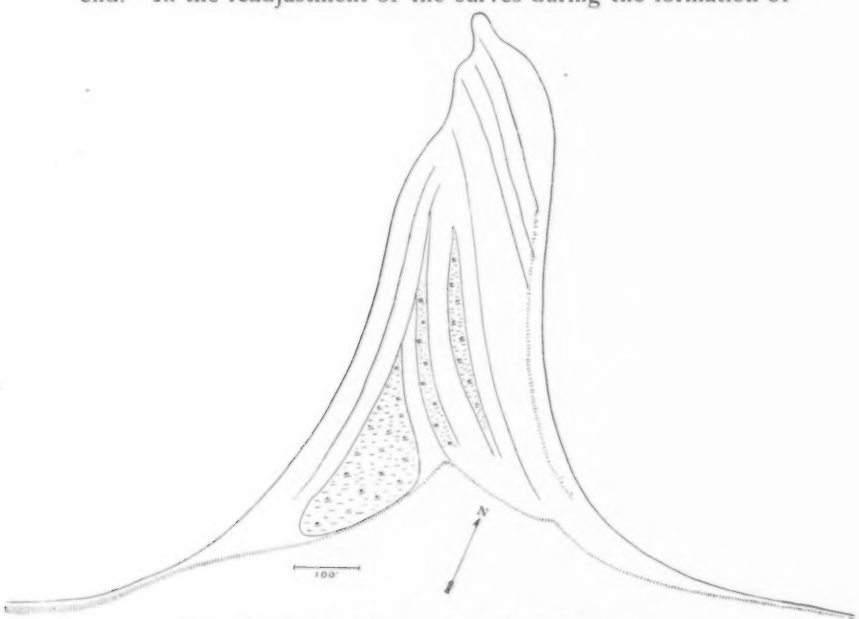

FIG. 6.—Sketch plan of Pleasant Point Foreland, May 23, 1903.

the seventh or modern beach the waves have cut through the sixth and fifth, and are now acting on the fourth near its shore end. On the west side traces of only one ancient beach could be found between the present modern beach and the triangular lagoon. It is assumed, in the counting, that this is the correlative of some one or more of the first six of the earlier beaches found on the east side. Both the beaches on the west side cut across the ends of the first three of the earlier beaches, and the modern one cuts across the ends of the other three as well. The fourth beach on the east, the highest and broadest of the series, rises

about 6 feet above present water level, or at least 8 feet above the bottom of the lagoon. The beach on the west is only about 2 feet high, except near the apex of the spit.

A reference to the general map will show that immediately to the east of the point we have a gap—the Upper Gap—in the side of the Bay of Quinte valley, through which storm waves from the open lake can have access to the bay. The waves which will have most effect on the shore are those coming from a little to the east of south, although the waves of a storm from the east or south will also be capable of effective work. On the other hand, the spit is exposed on the west only to waves traveling up the bay before a wind having a very limited distance in which to act. Hence we find that the larger waves from the open lake have been steadily carrying material around the point, and depositing it in the slack, but very deep, water behind. The point of the spit is now out as far as the 70-foot contour. The much larger size of these waves has been the important factor in determining the coarseness of the material of the eastern part of the spit, in piling it so high, in determining the amount which has been brought here, and in causing the spit to travel slowly eastward. The material which forms the west arm is in part derived from that brought by the bigger waves to the east side and subsequently carried around the point, partly by the same system of waves which brought it, but chiefly by the waves coming up the bay from the northeast at other times. Some of it is brought from the shores to the west. One record of the changes which take place at the apex of the beach under the action of

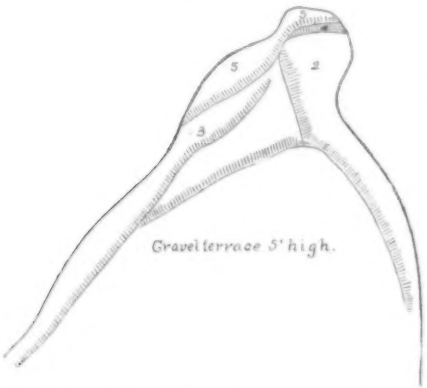

FIG. 7.—Sketch plan of about 100 feet of the apex of the Pleasant Point spit, May 23, 1903, showing the shifting beach ridges and terraces.

different storms is shown in the accompanying sketch. Material is transported very rapidly along the eastern side of the beach, in spite of its coarseness. Along the west the travel seems to be much slower because of the relatively small size of the waves.

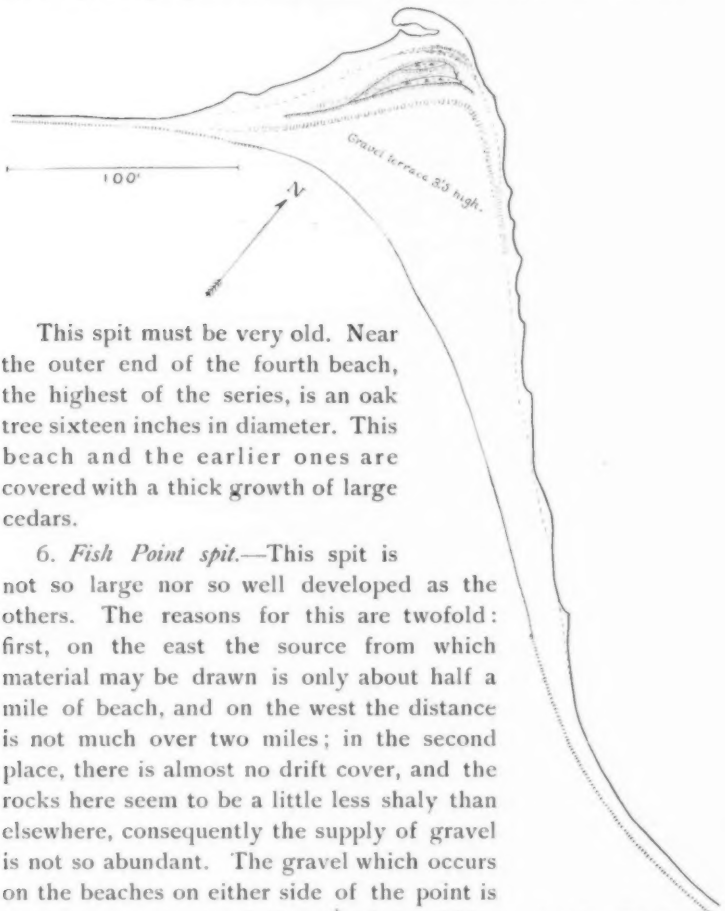

FIG. 8.—Fish Point Foreland, May 24, 1903.

This spit must be very old. Near the outer end of the fourth beach, the highest of the series, is an oak tree sixteen inches in diameter. This beach and the earlier ones are covered with a thick growth of large cedars.

6. *Fish Point spit.*—This spit is not so large nor so well developed as the others. The reasons for this are twofold: first, on the east the source from which material may be drawn is only about half a mile of beach, and on the west the distance is not much over two miles; in the second place, there is almost no drift cover, and the rocks here seem to be a little less shaly than elsewhere, consequently the supply of gravel is not so abundant. The gravel which occurs on the beaches on either side of the point is very coarse, many of the rounded pebbles exceeding two inches in the longest diameter, and there are numerous large plates up to ten pounds in weight. The gravel at the spit is smaller than elsewhere, that on the east

side probably a little coarser than that on the west. The spit, as a whole, resembles a cap which has been built by the gravels on the end of a minor salient of the mainland by the waves when readjusting the shore curves. The main portion of the spit consists of a large irregular or wavy topped terrace of coarse gravel, built out in front of the mainland. For the most part the earlier beaches have lost their individual identity. At the outer margin several of the later ones are still persistent, inclosing shallow lagoons.

The spit was particularly interesting as it exhibited several features, which are described in detail because it is thought that their mode of formation is an index of the way in which the large V bars and V terraces were built up. The eastern side of the spit at the water line had a serrate margin, there being ten distinct, well-marked minor cusps, which for convenience in description may be called cusplets. Each of these had a long, gently curving shore line on the side toward the advancing waves. The free end of the cusplet was joined to the main shore by a short, abrupt, concave curve. Sometimes the free end of the cusplet was drawn out into a sharp, well-developed point. The best-formed cusplets had a sharp median ridge extending down the axis, and often prolonged as an apical spine at the free end. The outer slope, toward the water, was very steep, at first almost a straight line, and then gradually curving around to the normal subaqueous beach curve. The inner slope was much flatter. The curve of the shore line of the individual cusplets was approximately adjusted to the curve of advance of the front of the waves which were building and shaping them (see Fig. 9). The finer gravel lay on the longer back slopes, the coarser fragments, often small plates rather than rounded pebbles, were concentrated on the steeper frontal slopes.

These serrations on the side of the spit seem to owe their origin to the attempt of the waves of a particular series of storms, coming from a nearly constant direction, to readjust the curvature of the shore line to the curvatures of their own fronts. Off shore the waters are very deep, and the shore line of the bay is yet in a very young stage of its development; consequently

the waves traveling obliquely toward the shore are not symmetrically and systematically retarded. The wave does not advance on the shore parallel to its front but comes up obliquely (see Fig. 9). The result is that the gravel was moved obliquely up the slope of the beach, and then obliquely downward with the return of the wave, but always with a resultant in a direction

FIG. 9.—Showing the relation of the wave-fronts to the serrate margin of the east side of Fish Point Foreland.

parallel to the shore. During the period of observation the débris moved along the long curve of the cusplets very rapidly, and then, when discharged into the deepest water at the free end, would either fall at once to the bottom, or might happen to reach the end just in time to be carried across the intervening space by the rush of the less retarded part of the wave which had not yet reached shore. Material would thus be rolled along the long slope by the breaking edge of the wave, but, when discharged at the free end, it was often bodily carried several feet past the

spine of the cusplet and up to the main beach by the more powerful, less retarded portion of the waves—there to be rolled slowly or rapidly along the long slope of the next cusplet, where the process was repeated.

The size of the cusplet in some cases seemed to be increasing, but several seemed to have reached a maximum stage. Given a constant material, the limit of size seems to depend upon the size of the waves and their periodicity.

These little cusps are formed during the period of a single storm, or series of storms, when the waves advance in an oblique direction on a previously evenly curved shore. Their formation and their symmetrical arrangement seem to be due to two factors. In the first place, very frequently the undertow is able to carry material down the slope of the beach a little farther than the front of the wave can move it up, within certain limits. Consequently, although some of the material moved up the slope by the front of the wave lodges, some of it moves down with the undertow, and a small percentage of this latter material may move out beyond the zone at which the next oncoming waves can move it up the beach. Hence there will be a slow but gradual accumulation just beyond this line, which in time will even modify the direction of the long shore currents. A second and more important factor in the production of these serrations along the shore is the development of nodal lines along which material tends to accumulate. Where the waves are advancing at an angle to the shore there will be a number of waves breaking at the same time at different points along the shore. As the spacing of the waves is nearly uniform, if the shore line were perfectly straight, these points of simultaneous wave-breaking would be equidistant from one another. On a curved shore the spacing will be systematic, but the distances between breaking points will not necessarily be equal. Now, the undertow which flows out from one wave as it breaks will interfere with the advance of the next following wave, if it meets that wave on that part of the shore where the orbital motion is nearly a straight line up the beach. This happens very frequently where part of a wave is retarded by a cusplet while the other

part passes the free end with little retardation. The result will be a tendency for the material moving down the slope with the undertow, and up the slope with the advancing wave, to be dropped at a symmetrically arranged series of points. The obliquely moving waves also move débris along the shore in the resultant longshore direction of the wave advance.

The result of the combined action of these different factors is that gradually a little bar is built out from the shore by which the waves attempt to readjust the curvature of the shore line to a curvature appropriate to their direction of advance. Because of the nearly uniform spacing of the waves, these bars will begin at a number of symmetrically arranged points. Because of the normal, uniform slope of the subaqueous floor, the maximum distance from shore at which the undertow can materially interfere with the advance of the next wave will be located at a nearly uniform distance off the initial shore line, and this will tend to limit the size of the individual cusplets. The size is also limited by the distance between the crests of the waves. The building of the cusplets further modifies the form of the shore line, the slope of the bottom, the direction of the advance of the waves, and the direction of the longshore currents; but with waves of constant size an equilibrium will be established, at which time the cusplets will have their maximum size. If the waves are irregular, cusps may not be formed at all.

The same waves which had built the serrate margin along the eastern side of this foreland had built a small flying spit at the apex. Between the free end of this small flying spit and the main beach a very small A-shaped point was also gradually built up. The waves coming from the east in the direction indicated by the arrows (Fig. 10) swung around the point, giving it the form shown in the figure. The fronts of the waves assumed the form of a series of helicoidal curves as they swung around the point as if on a pivot. As many as eight waves could be counted swirling around the west end of the flying spit at the same time, the moving crests looking not unlike the spokes of a gigantic horizontally rotating wheel. The relative positions of the successive wave-fronts are shown by the dotted lines in the figure.

Material which had rounded the extreme tip of the flying spit was actually carried across the narrow water space between the flying spit and the little conical point being deposited on the outside of

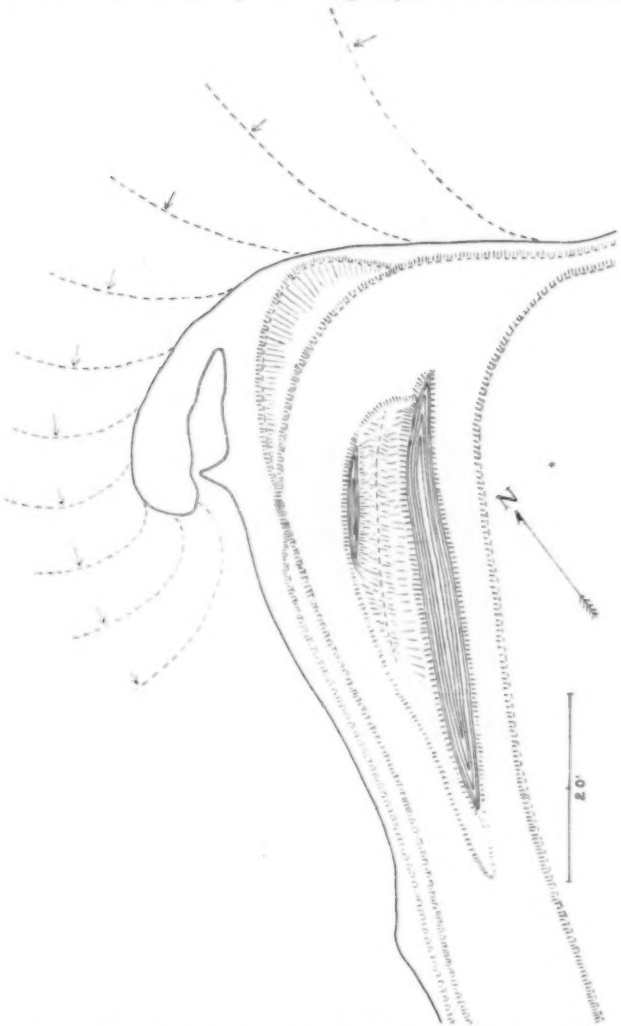

FIG. 10.—Sketch plan of the apex of Fish Point Foreland, May 24, 1903.

the cone. As each wave came in, the water in the small lagoon rose and fell. The outflowing current seemed to be the control which shaped the inner curves of the cone. A little farther to the west the same waves were increasing the size, rounding the ends, and otherwise modifying the two larger cusplets (Fig. 11), which,

FIG. 11.—Two well developed cusplets in the foreground, the apex of the small loop spit appears in the background. North side of Fish Point Foreland.

judging from their initial forms, had evidently been built some time before by a storm blowing from the west.

7. *Amherst bar.*—Waves rolling into the bay through the lower gap from Lake Ontario have built a long gravel bar off the east end of Amherst Island. This bar runs nearly north from the end of the island and is nearly two miles in length. Most of it is submerged, but near the island a portion rises as a sharp ridge several feet above water level. The eastern end of Amherst Island is low, and the shore is rocky. Most of the gravel forming the bar has been moved along the south shore of

the island by southwest storms off Lake Ontario. The portion of the bar that is above water level has a peculiar curved form, due to the many complex modifications which such a bar may undergo under the influence of minor storms. Some of these are well shown near the free end of that portion of the bar which rises above water level. On the south side of the free end we find two large, well-developed, south-pointing cusps, bounded by curves which are concave lakeward. These cusps seem to owe this form to the action of waves advancing from the southeast and the southwest at different times.

8. *Calf Island loop bar.*—Although not in any way associated with the Bay of Quinte, it seems desirable to include in these descriptions a reference to the loop bar off the east end of Calf Island. The island lies about four miles northwest of Stony Point, and half a mile to the west of Stony Island. Storm waves blowing down the lake naturally divide at the island and pass on either side of it. Coarse gravel derived from the limestone rock, by which the main island is underlaid, has been piled in two high ridges, one leading off from either side of the island. The two unite in a rather sharp point about 350 yards from the east end of the rocky part of the island. The crests of the bars are about 9 feet above water level, and between them is a deep, narrow pond. The south bar is about 60 feet wide, and has equal slopes on either side; the north bar is a little wider and more irregular.

Similar forms are to be looked for off the northeast ends of several of the other rocky islands in this part of the lake. Off the east end of Grenadier Island two long flying spits have formed, inclosing between them a shallow bay known as Basin Harbor. This bay is gradually filling up. The free ends of the two spits are curving toward each other, and, given time enough, we would expect them to unite. In the meantime, the inclosed basin will be partly filled by sand either washed in by the waves or blown in from the bars. The outer slope of the bars will still have the steep gradients of such forms; their height will depend upon the depth of the adjacent water. In time there will thus be formed off Grenadier Island a huge terrace, with running

bars, which in form will approximate in shape to the typical V-terrace and V-bar.

THE ORIGIN OF THE V-TERRACE AND V-BAR.

Four of the forms which have been described in the preceding paragraphs agree very closely, both in form and location, with Gilbert's description of the type examples in Lake Bonneville.[1]

In his descriptions of the type examples Gilbert notes that:

> They are built against coasts of even outline, usually but not always, upon slight salients, and they occur most frequently in the long narrow arms of old lakes.

In discussing the origin of the form he states:

> In some cases the two margins appear to have been determined by currents approaching the terrace (doubtless at different times) from opposite directions; and then the terrace margins are concave outward, and their confluence is prolonged in a more or less irregular point. In most cases, however, the shore drift appears to have been carried by one current from the mainland along one margin of the terrace to the apex, and by another current along the remaining side of the terrace back to the mainland. The contours are then either straight or convex.

The bars which border the terraces he attributes to a later period during a slight deepening of the waters of the lake, after the terraces had attained their full size. While the lake stood at the higher level, the linear embankments were built at the outer margins.

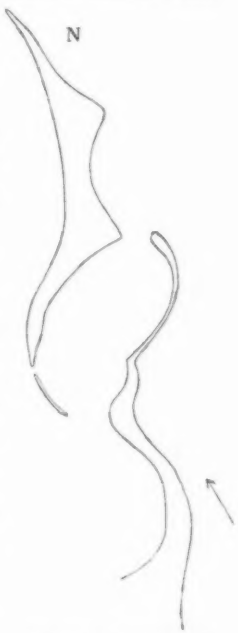

FIG. 12.—Sketch plan of about 500 yards at the apex of the portion of Amherst Bar above water level on May 25, 1903. Direction of wave advance shown by the arrow.

The author's studies of the forelands in the Bay of Quinte lead him to suggest the following hypothesis as to the mode of origin of the forms here described. In the first place, it must be noted that the level of the water in the bay varies

[1] U. S. Geological Survey, *Fifth Annual Report*, 1883-84, p. 98.

considerably with the seasons, being a little higher in late spring or early summer than at any other time. The level of Lake Ontario also changes considerably during a season. Both of these factors may have some bearing on the formation of the terraces and bars. The changes in level due to the larger seiche waves must occasionally be even greater than these seasonal changes. None of the forms show any evidence which could be interpreted as being due to these seasonal or periodical changes in level.

In a previous paragraph a detailed description was given of the process by which small cusps were produced along a shore. Under the continued action of waves of moderate amplitude the dimensions of these small forms would gradually increase, and eventually they would reach a size which could easily control the shore currents and wave direction of even moderate storms. In the present instance the bay is completely frozen over from about the middle of November until the first of May. During the season of open water the only effective storms are those which chance to be blowing up or down the bay. To be effective, they must have a constant direction, for a considerable interval of time. Hence, while moderate breezes which generate small waves are frequent, violent storms which can modify the work of all previous lighter winds and waves are rare. When they do come, their first work would be to readjust the shore curves developed during the previous interval. The chances that they would preserve a suitable direction long enough to efface the work of the previous, more or less contsant, but less energetic, storms are very slight. The construction of the small triangular terrace may in part be attributed to the leveling action of some such storms as these. In all observed cases, although the terrace under the triangular lagoon had a slight slope outward, its slope was not so great as that of the adjacent shore a little distance on either side of the sand spit; from which it is inferred that there had been some filling. Whether such a process could produce a very much larger terrace than those noted is uncertain. In other cases the portion of the terrace included between the bars may have been partly filled in by the

waves themselves after the formation of the bars. Such a terrace is in course of construction off the east end of Grenadier Island. A similar process is causing a great deal of inconvenience at several harbors along the north shore of Lake Ontario, where two artificially constructed bars in the shape of piers inclose a harbor which periodically fills with sand that has to be removed by dredging.

In some cases the inner lagoon may have been filled after the bars were formed, by ordinary processes of transportation which tend to fill hollows and lessen the grade of steep slopes.

The size of the terrace would also depend upon the size of the water body, and upon the character of the material. The tendency will always be for the waves bringing the supplies of material to heap this up in the form of a bar. In the later stages, when the accumulation has become considerable, the larger storms would not be able to efface these bars, though they will reshape them and pile the material higher on the outer margin. On the outer side of a bar, below water level, the material has a gentle slope to below wave base. Beyond this the inclination of the front slope will be the angle of repose for material of the kind. In the case of all the forms on the Bay of Quinte, where the water drained off it would be found that the forelands would have steep frontal slopes, with an elevation in several cases of about 60 feet. The top would be a nearly flat terrace, with gently curved edges, and rising above it at a little distance from the margin would be the sharply defined rimming bar.

In the smaller examples the same waves which build the one side of the foreland carry material around the end of the spit and distribute it for a shorter or longer distance, according to their size, on the other side. On some occasions the same waves may shape both sides at the same time, but usually it is found that the adjacent sides are shaped alternately. In some cases the greater proportion of the material comes from one side, and its redistribution on the opposite side of the spit is effected by other waves from a different direction and at another time. In the case of Point Pleasant spit it seems to be slowly shifting eastward, as material brought from the southeast accumulates on

that side. At the same time less rapid erosion is taking place on the west side under the action of less violent waves.

CONCLUSIONS.

In conclusion, it may be stated that the forelands here described seem to have been built wholly by the action of waves acting either directly or indirectly in association with longshore currents which were intimately associated with them.

The location of the forelands is associated with some more or less salient feature of the coast which has influenced the direction of wave advance and the course of longshore currents, and has localized the effective transporting action of both.

Their formation is due to the control exercised on wind direction and on wave direction by the form of the bay. The form of the forelands is due to the peculiar character of the long, narrow water body on which they are situated, the conditions being such that only certain classes of storms can be effective agents in the shore transportation. The immature character, and consequent imperfect adjustments of sub-acqueous portions of the shore is an important control in wave-work.

The V-terrace and the associated V-bar upon it, in the instances here studied, are regarded as products of the same agent, and do not necessarily imply a change in water level. The evidence from Point Pleasant spit implies that there has been no significant change in level during the long period of growth of the greater part of the spit.

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A CONTRIBUTION TO THE STUDY OF THE INTERGLACIAL GORGE PROBLEM.[1]

Topography of the Finger Lake region.—The topography of the Finger Lake region is too well known to American geologists to require any detailed description here. The rocks, which are almost wholly Devonian, consist of great deposits of shale and sandstone, with a few thin beds of limestone. These rocks have never been greatly disturbed and lie nearly horizontal, with a slight southward dip. In the Cayuga Lake district there is a series of gentle folds which cross the lake valley in the east-west direction. A glance at the even sky-line presented by the hill-tops shows that the region is a great plateau. This plateau has been so deeply dissected that it resembles a mountainous country, with the hills often rising several hundred feet above the valley bottoms. About fifteen miles south of the heads of the lakes is a dissected divide that Professor Tarr[2] has characterized as being "high and diverse in topography." From the divide the plateau slopes northward and merges into a drift-filled region at the northern ends of the lakes. Here, doubtless, there was an escarpment in preglacial times, but it is now nearly obscured by drift.

Cayuga Lake valley.—From the divide at Spencer Summit the valley of Lake Cayuga extends northward a distance of nearly fifty miles, when it is lost beneath the drift. Professor Tarr[3] has called the divide at Spencer Summit a divide of "destructional origin." He considers the depth of the drift here to be slight; and from the steepness of the walls he infers that the divide must have been higher in preglacial times, "having been lowered

[1] This paper was originally written as a thesis for the master's degree at Cornell University. Since the preparation of the original manuscript enough new information has been secured to warrant a slight revision, and therefore some changes have been made. The writer is indebted to Professor R. S. Tarr for many valuable suggestions concerning the field investigations and the preparation of the original paper.

[2] R. S. TARR, *Bulletin No. 5*, Geological Society of America, p. 340.

[3] *Ibid.*, p. 341.

by glacial erosion." There is also good reason for believing that the divide has been lowered by stream erosion. The ice in its advance would close the outlet of the lake valley, causing a lake to be formed between the ice front and the divide. The drainage of this lake across the divide would continue until the ice had advanced to the divide. In receding the ice would again cause the formation of a lake in the valley, which would exist from the time the divide was uncovered until the ice retreated far enough to uncover a lower outlet. The drainage across the divide would naturally tend to lower it. The amount of erosion would vary with the length of the time. The presence in Cayuga Valley of the well-developed terminal moraine of the Wisconsin glacial epoch points to the existence of an ice-dam in the valley for a long time. This fact points to the probability of the divide having been considerably lowered by stream erosion. The effect of the drainage across the divide would be influenced by the relative altitude of the northward- and southward-flowing streams. If the southward-flowing streams had cut considerably below the level of those flowing northward, the water would fall into the deeper valleys, and the divide might be destroyed in a very short time by the recession of this waterfall. If, as seems more probable, the northward-flowing streams had reached the lower level, the removal of the divide would be much slower. On this point Professor T. L. Watson has said:

> It can hardly be doubted that the Laurentian tributaries were the stronger streams, therefore encroaching upon the territory of the other system, and thereby causing the southward migration of the divide.[1]

We should also bear in mind that there is a possibility of a differential uplift having rejuvenated the Laurentian streams just before the glacial period. Mr. M. L. Fuller[2] failed to find evidence of this uplift in the area covered by the "Elkland-Tioga Folio":

> It has been frequently urged among geologists that the advent of the earliest Pleistocene ice-sheet was preceded by a general uplift of the northern half of the continent, affecting the surface throughout the northern por-

[1] "Some Higher Levels in the Post Glacial Development of the Finger Lakes," *Report*, N. Y. State Museum, Vol. I (1897), p. R. 68.

[2] M. L. FULLER, "Elkland-Tioga Folio," U. S. Geological Survey, p. 7.

tion of the United States. In western Pennsylvania, however, the presence of Pleistocene river gravels on rock terraces several hundred feet above the bottom of the present gorge of the upper Allegheny River indicates that the last stage of the active erosion did not begin there until after the first ice invasion, though the uplift and the inauguration of the erosion in the lower reaches of the river may have been somewhat earlier. The uplift recorded by the rock terraces immediately adjacent to the Susquehanna in the eastern portion of the state is of questionable date, but would appear to be of late Tertiary or early Pleistocene age.

In the Elkland-Tioga region there appears to be a slight notching in the bottom of the old valley of Pine Creek and some of its tributaries, but it is believed that this was not produced until after the southward deflection of the lower portion of the creek through the gorge south of Ansonia. This diversion, as will be described more fully in the discussion of the earliest glacial stage, was probably due in great measure to the accumulation and overflow of waters ponded in front of the advancing ice-sheet, and the consequent reduction of the divides and the cutting of a new channel in which the stream persisted even after the ice had disappeared. The notching of the bottom of Pine Valley and its branches was a result of the diversion through the new and lower channel, and affords no evidence of uplift.

The Elkland-Tioga region is not far from the Finger Lake region. It is, however, on the south side of the divide, and includes some of the streams which are tributary to the headwaters of the Susquehanna River. If rejuvenation had effected the Laurentian drainage, this would tend to increase rather than diminish the advantage of the northward-flowing streams over those flowing southward.

The hills, which rise steeply at the southern end of the lake valley, become lower and more gently sloping as you pass northward. The valley also widens rapidly toward the north. While a mature stream valley ought to become wider and the walls more rounded toward the mouth of the stream, the change here is so rapid as to suggest that there must be some other explanation to account for a part of the difference. One cause which has probably contributed to this end is the northward differential depression which occurred at the close of the glacial period. If this depression amounted to no more that two feet per mile, it would have made a difference of one hundred feet in the relative height of the land at the ends of Cayuga Valley. It has been suggested that the difference in the topography at the

two ends of Cayuga Valley is due to a difference in rock texture.[1] The southern part of Cayuga Valley is cut in the hard, durable Portage sandstone, while farther north are the soft Hamilton shales which break down much more easily when exposed to the agents of weathering. Another point of considerable, though undetermined, importance in this connection is the intense glaciation to which the northern end of the lake valley has been subjected. As suggested by Dr. G. K. Gilbert,[2] the belt in which the northern end of the lake lies has been much more intensely scoured by the ice than the belt south of the lake. The width of the lake varies from about a mile near its southern end to about three miles near Aurora. The surface is 378 feet A. T., and the greatest depth is 432 feet. For considerably more than half its length the bottom of Cayuga Lake is below sea level. The drainage of Cayuga Valley is northward into Lake Ontario.

Direction of preglacial drainage.—While some of the earlier writers believed that the preglacial river which occupied Cayuga Valley flowed southward, all the later students are agreed that it drained northward into the Ontario basin. The hypothesis of a northward preglacial drainage is based on the following lines of evidence: the general northward slope of the land; the wider and more mature aspect of the valley as one passes northward from the divide; the increasing number of tributaries near the divide; and the fact that the bottoms of the mature tributaries become lower from the divide northward. While all these lines of evidence have been affected by the various changes accompanying glaciation, it has not been sufficient to destroy their value as evidence in this connection. Since there are no facts opposed to the theory of a preglacial drainage toward the north, we may regard the hypothesis as established.

Postglacial gorges.—With few exceptions, all the tributary streams which occupy mature preglacial valleys enter the main valley through narrow, rock-walled, postglacial gorges contain-

[1] *New York Geological Survey of the Fourth District* (1843), p. 225; *Monograph XLI*, U. S. Geological Survey, p. 79.

[2] Paper read before the Geological Society of America, December, 1902.

ing many rapids and waterfalls. The length of these postglacial gorges is usually less than three miles; and the amount of fall varies from about 100 feet to over 500 feet per mile. The descent is usually accomplished by means of a series of cascades, though

FIG. 1.—Taghanic Falls.

in a few cases there are cataracts of considerable height. Taghanic[1] Falls, the highest, measures 200 feet. Many of these falls have developed on account of an alteration of hard sandy layers with layers of soft, easily eroded shale. A few cataracts

[1] This spelling is in accordance with that on the Genoa atlas sheet of U. S. Geological Survey.

also occur over the Tully limestone, which caps the soft Hamilton shales. In general, the amount of fall in the postglacial gorges diminishes toward the north, although there are some exceptions to this rule.

The principal cause for this gorge condition, in the lower part of the tributary valleys, is the fact that the streams have been turned from their old channels and forced to cut new ones. Another cause which has contributed to the same end is the widening and deepening of the main valley by glacial erosion. In some cases the streams have possibly been turned aside by a moraine dam, but the most common obstructions are the deltas deposited in the ice-dammed lakes[1] which formed in front of the continental glacier. These lakes fell to successively lower levels when lower outlets were uncovered, and the streams continued to flow along the course occupied when the lakes fell. The new channels are mostly south of the old course, and Professor Tarr[2] has attributed this to the effect of the prevailing north winds on the waters of the extinct lake. Coy Glen, being exposed to the south winds and protected from the north winds, lies north of its old channel.

Interglacial gorges.— In every case where the streams have been turned aside in the manner just described there is a lower course in the same broad valley, which is itself a gorge. Professor Tarr has already called attention to these gorges in his *Physical Geography of New York*.[3]

Interglacial (?) gorges.—In central New York there are numerous gorges which are broader than the postglacial valleys and partially obscured by glacial till, showing that they were formed either during preglacial or interglacial times. This class of valley is especially well illustrated in Six Mile Creek, where its relation to the broad, mature preglacial valley is well shown. In one case, near Taghanic Valley, lake beds containing fresh-water fossils have been found beneath the till.

One naturally thinks of these gorges as being interglacial in

[1] H. L. FAIRCHILD, *Bulletin VI*, Geological Society of America (1895), pp. 353–74; T. L. WATSON, *Report*, New York State Museum (1897), pp. 55–117.

[2] *Physical Geography*, N. Y., p. 177. [3] Pp. 178, 179.

origin, and this explanation seems, at present, the most probable; but all that can now be said with certainty is that they antedate the last advance of the ice. The question of these gorges has a very important bearing upon the whole subject of the drainage history of central and western New York. Were the gorges due to interglacial conditions or to an uplift of preglacial times? Leverett refers to similar gorges in his monograph[1] on *The Glacial Formations and Drainage Features of the Erie and Ohio Basins.*

> The valleys of this hilly country present marked differences in topography. In some valleys the slopes from top to bottom have a mature aspect, while in others the upper part of the slope is mature, but the lower part is gorge-like and youthful in appearance. The phenomena suggests at once that some valleys have remained below the level of stream-cutting, while others have been undergoing a marked trenching. In these which have been deepened, the old valley bottoms are traceable along the brow of the rock gorges or canyon valleys, for the old valleys are generally broader than the new ones. In some cases, however, the new valleys occupy the whole width of the bottoms of the old ones, and there is only the change in the angle of the slope of the valley bluff to mark the depth of the old valley. There is, in some valleys a series of complex terraces or rock shelves, of which one set or system stands at the brow or border of the canyon valley, and the others at higher altitudes. There are also, in some cases, rock shelves inside the trenches of the canyon valleys. The set of trenches standing at the brow of the canyon valley is, however, a far more persistent feature than any of the others, and it is this set which receives chief attention in the ensuing discussion of drainage systems. It seems to mark a true gradation plain, formed when the stream was in condition between degrading and aggrading its bed.

All the preglacial tributaries of Cayuga Lake Valley which have been examined have gorges cut in their bottoms, and these gorges are wider, and in many cases deeper, than the postglacial gorges. The approximate width of the drift-filled gorges can usually be ascertained without much difficulty. On account of the drift-filling, the depth is not readily determined; however, Evans, who studied Taghanic carefully, mapped the old valley bottom as continuous above the level of Lake Cayuga.[2]

Ten Mile Creek.—Ten Mile Creek, despite its name, is only about six miles in length. It rises near the village of Danby and flows a little west of north, entering the Inlet about two miles

[1] *Monograph XLI*, U. S. Geological Survey, p. 80.

[2] R. M. Evans, Thesis on Taghanic (1897), Map. II.

south of Ithaca. The stream occupies a broad, mature valley with gently sloping sides. This valley divides at Danby, the branches becoming narrower and the walls steeper for some distance beyond the village. While Ten Mile Creek now rises at Danby, there is evidence that the preglacial divide was farther south. Danby Creek, which rises near the east branch of Ten Mile Creek, flows southward through a valley which gradually narrows for a distance of three miles and then widens again. Michigan Creek, which heads near the west branch, flows through a similar valley; but in this case the narrowest part of the valley is only about two miles from the source of the stream. The narrowing of these mature valleys cannot be explained on the ground of rock texture, for the rocks here are of uniform character. The narrowing may be explained by supposing that the narrowest part represents the divide between these streams at the time the broad valleys were being formed. The divide hypothesis is strengthened by the fact that the highest hills are on either side of the narrowest parts of the valleys; and by the additional fact that the present divides are clearly of constructional origin, being composed of low drift ridges. The drift ridges are within the limits of the region covered by the last ice-sheet; and the present location of the divides was determined by the material deposited at the ice-front.[1]

About a mile from the Inlet, Ten Mile Creek enters a narrow postglacial gorge; and in less than a mile it falls, by a series of rapids and cascades, through a vertical distance of about 420 feet. The highest falls are the two cascades near the edge of the inlet, which together measure 190 feet. Running nearly parallel to this gorge is a drift-filled gorge, which is much broader and deeper than the postglacial gorge, as shown by sections 1 and 2. The buried gorge is now occupied by a small stream which has removed the drift down to 520 feet A. T., but has not reached the rock bottom. The width of this gorge is 250 yards; its depth is not known, but the north wall rides 156 feet above the drift which forms the bed of the present stream. The lower end of this stream is through a small postglacial gorge, cut in the north

[1] For location of the divides, see Map I.

wall of the filled gorge. There is a rock terrace[1] on the south side of the buried gorge at 620 feet A. T., which probably represents a former level of the stream, for there is a tributary gorge on the north side near the cemetery which enters the main gorge at about the level of this terrace. The tributary shows as a gap in the wall of the main gorge, just below the cemetery and it is crossed by a small stream just above the cemetery. A short dis-

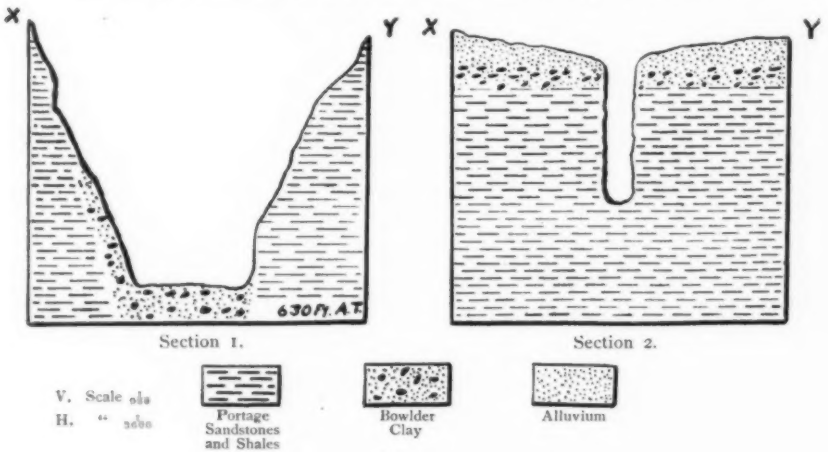

FIG. 2.

tance from the inlet the present stream crosses a small buried gorge, which must have been another tributary, for the rock is practically continuous at 720 feet A. T. between the old gorge and the postglacial gorge.

If we look upstream for the continuation of the large buried gorge, we find that it appears just above the delta which was built by the stream in Glacial Lake Ithaca.[2] Above this delta the gorge can be traced nearly a mile to where it is finally obscured by the drift. In that distance the stream has cut two small postglacial gorges around drift obstructions which block

[1] The writer has begun a study of these rock-shelves which he hopes will lead to an explanation of the direction of flow, and at the same time elucidate some other points. The photograph taken in Six Mile Creek shows two terraces.

[2] T. L. WATSON, *Report*, New York State Museum (1897), pp. 155–117.

the main gorge. One of these postglacial gorges is shown on Map II.

Map II comprises an area 1,000 yards long, and from 250 to 600 yards wide. The lowest part of the map is at the city reservoir, 880 feet A. T. The contours were mapped on either side of the stream up to 1,000 feet A. T. Above the 1,000-feet contour the surface rises very gently to the divides between Ten Mile Creek and the neighboring streams. There are three ridges on the map which extend nearly east and west, and rise to a height of 100 feet above the stream. Each ridge is composed partly of drift and partly of rock covered with drift.

Channels of Map II.—The stream enters the map through a broad drift floored channel, and, after crossing the rock in the southern ridge through a narrow postglacial gorge, it enters another drift-floored channel, through which it flows to the city reservoir. Below the reservoir the stream flows through the narrow postglacial gorge described earlier in this paper. In addition to the channels now occupied by the stream, there are four other channels within the area of Map II. Two of these channels pass beneath the southern ridge, one east of the present stream (see map, *A*), and one west of the present stream, and just south of the house (see map, *D*). There is a channel beneath the middle ridge west of the rock outcrop (see map, *B*), and one beneath the northern ridge, east of the rock outcrop (see map, *C*).

Evidence of the existence of channels.—The general evidence of the existence of these channels is of two kinds: (1) the trend of the rock outcrops; (2) the existence of well-defined indentations on the upstream side of each of the ridges. These indentations were produced by the stream swinging against the soft drift ridges. The drift was not entirely removed from the channel, because the rock in the ridges prevented the formation of a broad meander within these channels. In the case of the channel (*D*), west of the postglacial gorge, the drift ridge has been so badly eroded that the rock-walls show above it, and near the southern end of this channel the wall has been exposed down to the bottom of the channel (Plate V). The hypothesis of a

channel (*A*), east of the postglacial gorge, is strengthened by the fact that the channel west of the postglacial gorge is too narrow and too shallow to be the continuation of the broad channel south of the ridge. The existence of a channel (*B*) beneath

FIG. 3.— Terraces in the drift-filled gorge of Six Mile Creek.

the middle ridge is very apparent in the field; and is fairly well shown by Plate VI. A boring made on the top of the ridge to a depth of ten feet did not strike rock, although the bottom of this hole is more than twenty feet below the highest rock in this ridge. The channel between the middle and north ridges seems rather narrow to be the continuation of the broad channel on the east side of the map, and the well-defined indentation (see Plate

VI and Map II, *C*) on the south side of the north ridge, points strongly toward the existence of a channel beneath the ridge.

Nature and size of channels.—The fact that the rock rises perpendicularly above each of these channels indicates that they are gorges, and the rock in each of the ridges forms a rock island. The postglacial gorge is 25 yards wide, 50 yards long, and 90 feet deep. The gorge south of the southern ridge is over 250 yards wide and 100 feet deep. The drift has been removed down to 910 feet A. T. without exposing the rock bottom. The gorge (*D*) just south of the house is 35 yards wide and 90 feet deep. It has its bottom at 910 feet A. T. This is at the same time level as the bottom of the postglacial gorge. The gorge running east from the house is 125 yards wide and 110 feet deep. Its bottom, as indicated by borings near the house and between the rock in the two ridges, is below 890 feet A. T. The gorge just south of the reservoir is more than 175 yards wide and it has been cut to 880 feet A. T. without encountering rock. This would give it a depth of 120 feet. The gorge between the middle and northern rock islands, is 125 yards wide and has a drift bottom 900 feet A. T. The outcrop along the stream at the east end of this gorge, is an extension of the rock in the northern ridge and it was probably originally at the same height, having been lowered by the swinging of the stream against it. It now stands 905 feet A. T.

The arrangement of the sections of gorges into a series of continuous gorges depends upon size, depth, and position. Gorge No. 1[1] passes beneath the southern ridge, east of the middle ridge, and east of the rock in the northern ridge. From the slope of the rock-floor of the broad valley, as indicated by well records and rock outcrops, this channel must lie approximately in the axis of the broad valley of Ten Mile Creek, already described. Gorge No. 2 passes beneath the southern ridge, westward past the house, beneath the middle ridge, and west of the northern ridge. That this gorge could not pass between the middle and northern ridges is shown by the fact that its bottom

[1] The numbering is for convenience only, and does not indicate the supposed chronological order of formation.

is lower than the low rock outcrop which extends along the eastern edge of this channel. We still have left Gorge No. 3 and Gorge No. 4. These gorges may possibly belong together, though that is by no means certain. By taking the low ridge of rock east of the stream as one edge of Gorge No. 4, we can reduce its width to 75 yards, but it is still nearly three times as

FIG. 4.—A view in the drift-filled gorge of Ten Mile Creek.

wide as Gorge No. 3, and it is also more than 10 feet deeper. If, however, we assume that there was a fall somewhere between the two gorges, it would account for the difference in depth; but this assumption does not explain the difference in width.

Downstream extension of these gorges.—All these gorges must have entered the inlet through the broad gorge below the reservoir, which lies north of the postglacial gorge, for the rock-wall of the Inlet Valley is continuous for two miles on either side of the drift-filled gorge, except where there are postglacial trenches. It is possible that there is a local divergence of the small

drift-filled gorge. The stream which cut this small gorge may have turned aside and entered the broad drift-filled gorge through one of the channels which were mentioned earlier in this paper as being tributary to this gorge.

Origin of the rock islands.—As already shown, there are three rock islands on Map II. In considering the origin of the rock islands, the first question is: Could they have been formed during the normal stream development? A stream abandons its old course and takes a new one when ox-blow lakes are formed; but this happens when the stream is flowing on a flood plain, where the work of cutting across a spur is comparatively easy. In the case which we have to consider the rock is hard enough to offer considerable resistance to stream erosion. Moreover, the shape of the rock island is a serious objection to this theory. If they had been formed by a stream meandering, they should be rounded on the upstream side. Reference to the map will show that all of the rock islands are cut off squarely on the upstream side.

A second way in which rock islands may be formed is by lateral swinging of two streams until they cut through the divide which separates them. If the rock islands had been formed in this way by the uniting of the main stream and a tributary, they should taper to a point on the upstream and downstream sides. None of the rock islands have this form. In the case of the southern rock island, this hypothesis would meet with another objection from the fact that the rock-wall of the old gorge is continuous for one-half mile above the area of Map II.

From what has just been said it seems impossible to attribute the rock islands to normal stream action. Another possible hypothesis is that the rock islands have been formed as a result of glaciation. In this connection, two possibilities arise. Some of these gorges may have been overflow channels of glacial lakes, or the stream may have been forced to cut new channels around glacial deposits which obstructed its former course.

Can any of the gorges be the overflow channel of the glacial lakes? The gorges cannot be the overflow channels of a glacial lake, for there is no place where a lake could form with an outlet at this point. Any lake formed in front of the ice in the

inlet would drain over the divide at Spencer Summit, and the drainage of a small lake in Ten Mile Creek valley would naturally have to pass over the divides, not along the axis of the valley where these channels are located. For this reason, any gorges which would be formed as overflow channels ought to show on the divides, where a careful search has revealed none.

FIG. 5.—Looking down stream. Postglacial gorge of Map No. II on the right. Gorge D on the left.

Could the gorges have been formed interglacially? After glaciation, streams naturally begin to flow along the lowest courses. If the drift deposit is great enough to obscure much of the preglacial topography, the streams may take very different courses from those occupied preglacially; but if the amount of drift-filling is slight, they will naturally follow preglacial drainage lines. There may be partial abandonment of old drainage lines, as in the Genessee River,[1] or the stream may follow

[1] An enumeration of the cases of reversions of drainage which have been described by various writers would be too large an undertaking for the scope of this

approximately its preglacial course. It is possible, then, that these may be interglacial channels, but it would be just as impossible to have them all formed in one interglacial period as to have them all formed during normal stream development.

The hypothesis that some of the gorges were cut because of drift obstructions requires no different conditions from those existing in scores of places near here. Ten Mile Creek has been forced to cut three short postglacial gorges, because of such obstructions. The acceptation of the above hypothesis calls for a greater number of epochs of deglaciation than has heretofore been recognized in this region; but when we consider the great complexity of drift deposits, which has been recognized elsewhere, we do not feel that it is necessarily an objection. This hypothesis has no facts opposed to it, while all the others are open to objections which arise from conditions in the field; therefore we may regard it as established.

Age of the gorges.—A considerable lowering of the divide between the Cayuga River and the northward-flowing streams might have produced a rejuvenation of the streams tributary to Cayuga Valley. There is, however, little doubt that the Laurentian streams were stronger than the Susquehanna; consequently such a rejuvenation at the time of the first glacial invasion is improbable. What may have been the exact conditions governing the erosion at the divide during the remainder of the glacial period is, as yet, unknown.

Ten Mile Creek was a small tributary near the source of the preglacial Cayuga River, and would not feel the effect of an uplift until long after the rejuvenation had begun in the lower reaches of the stream. It is also questionable whether the uplift occurred long enough before the glacial period to permit the rejuvenation of the entire Laurentian drainage before its lower reaches were obstructed by ice. Nevertheless, the possibility of such rejuvenation must not be ignored.

paper. Among the best known and most extensive are those of upper Ohio, described by CHAMBERLAIN AND LEVERETT, *American Journal of Science*, Third Series, Vol. XLVII, No. 280, pp. 247–82. For descriptions of local reversions see *Physical Geography of New York* (1902).

While we cannot eliminate the possibility of a preglacial rejuvenation, we can limit the effect in Ten Mile Creek valley. The bottom of the broad valley in Ten Mile Creek is about 720 feet A. T., and there is a shelf in the drift-filled gorge at 620 feet A. T. A differential uplift increasing at the rate of three feet per mile (which would be a fair estimate) to the northeast might cause trenching to 620 feet A. T. without producing a rejuvenation of the streams of the "Elkland-Tioga Folio." To permit erosion to the lowest known point in this gorge would call for an uplift twice as great, while to reach the lowest known depth of any of

FIG. 6.—A view of the middle ridge looking down stream.

the gorges would require an uplift which would effect the streams south of the divide. Therefore, it seems safe to conclude that the main trenching of the broad valley was interglacial, and that in the case of Ten Mile Creek the preglacial uplift did not cause the stream to cut below 620 feet A. T. There is considerable evidence that the broad valley of Six Mile Creek contains two drift-filled gorges with their bottoms below 540 feet A. T. This fact would seem to indicate at least two periods of deep trenching after the first glacial invasion.

The length of the deglaciation intervals.—In considering the length of the intervals of deglaciation, we are confronted by a great many difficulties. One of the most troublesome points is our lack of knowledge of the depth of the various gorges. Another difficulty, which is almost equally troublesome, is the uncertainty as to their chronological order. From the fact that

the buried gorge (*D*) south of the house has its bottom at 910 feet A. T., while all the others have been excavated to a still greater depth, we may conclude that excavation of the gorges to their greatest known depths would require a large amount of erosion since the glacial period. If all the gorges are interglacial, the ice must at one time have retreated far enough to permit gorges to be cut down to, if not below, the present lake level. This would probably require a northward drainage. A comparison of the relative widths and depths of the various gorges shown on Map II brings out the fact that the amount of erosion required to excavate the buried gorges was considerably greater than the amount accomplished in postglacial times. This subject is complicated by the fact that the drainage basin of Ten Mile Creek has been reduced in postglacial times; but even making a large allowance for this reduction in drainage area, we may safely say that the shortest interval of deglaciation was probably fully as long as the postglacial time, while the others were considerably longer—in at least one case, several times as long.

Cause of the gorge-cutting.—In the formation of the broad valleys the streams must have reached base level. The only thing that could bring about rejuvenation of the streams, resulting in gorge-formation, is an uplift of the land. This uplift must have been of long duration, even though the streams may have found some of their work of degradation, below the old valley floors, accomplished by glacial erosion. The amount of this uplift cannot be determined; but from the fact that the buried gorge of Six Mile Creek has been cleared of drift down to 420 feet A. T., without reaching rock bottom, it follows that the uplift must have been sufficient to permit the stream to cut below that depth. The buried gorge of Butternut Creek, on the west side of the Inlet Valley, is over 250 feet deep; hence the amount of uplift must have been at least 250 feet. Since Butternut Creek is at present flowing 250 feet below the old valley floor, we may also assume that the postglacial altitude is probably fully 250 feet greater than the altitude when the broad valleys were formed.

Summary.—Briefly summarized, this paper is intended to show the existence of a series of complex gorges which are considered interglacial. The minimum number of epochs of deglaciation is two; the maximum number, four. The amount of ice recession was probably sufficient, in at least one case, to permit a northward drainage. The length of the epochs of deglaciation can be only roughly estimated, but the shortest was probably as long as postglacial time, and the others were doubtless much longer. The main trenching of the broad valleys was interglacial, and the minimum amount of interglacial elevation is placed at 250 feet. The land is probably more than 250 feet higher at the present time that it was during the time of the formation of the broad valleys of Cayuga Lake region.

GEORGE C. MATSON.

CHAMPAIGN, ILL.

AN INTERGLACIAL VALLEY IN ILLINOIS.

In this paper it is our purpose to trace the complex history of the present Embarras River valley, in southeastern Illinois, which lies partly on the newer Wisconsin drift and partly on the older Illinoian drift, crossing the terminal moraine of the former about midway of its course. North of the moraine the Embarras Valley is entirely postglacial, with little relation to any former valley. South of the moraine the youthful postglacial valley, as far as it extends, lies within a wider and more mature interglacial valley, which, in turn, usually lies within a still more mature preglacial rock valley.

There is evidence in Illinois and vicinity of several advances and retreats of the ice within the glacial period. During each retreat the melting of the ice freed rock waste, which had been carried along beneath the ice or frozen into the glacier, and deposited this waste as a sheet of till over all the land uncovered by the melting away of the ice. One of the oldest of these till-sheets is the Illinoian, now exposed over most of the southern and western parts of the state, but concealed by subsequent sheets in the northeast, the most extensive of which is the Wisconsin. In the southern two-thirds of the state the Illinoian and Wisconsin sheets are apparently the only ones represented, and their common boundary is the great terminal moraine, built during a prolonged halt of the ice-front at its farthest advance in the Wisconsin stage, and called here the Shelbyville moraine. The time between these two ice invasions, represented by the two drift layers, corresponds with two or more stages represented elsewhere by differentiable till-sheets, but known here only by erosion and weathering in the older drift. In other words, in southern Illinois, we have an old till-sheet extending far south, the Illinoian; a much younger till-sheet extending southward about to Paris, Mattoon, and Shelbyville, the early Wisconsin; and a strong terminal moraine lying along their common boundary. Fig. 1 shows the distribution of these features. For

convenience the time between the two glacial stages mentioned may be called an interglacial epoch, remembering that in other places it may be broken up into several stages of advance with shorter interglacial stages.

FIG. 1.—Cartogram showing distribution of Early Wisconsin and Illinoian Drift and the Shelbyville moraine and others, also the position of the Embarras River with reference to these areas. Initial letters for towns and cities mentioned in text. Adapted from Leverett, Ill. Glac. Lobe. Monog. 38, U. S. G. S.

Since the general slope of the state is from the north to the south, most of the streams flow in that direction, and of those taking their sources on the new drift several necessarily break

through the terminal moraine and proceed across the old drift to the Wabash, Ohio, or Mississippi Rivers. Among these streams which rise within the moraine loop and find their way out through it is the Embarras, to which the study now turns Rising in several more or less swampy regions, or from tile drains in Champaign county, and receiving several small streams en route, the Embarras proceeds southward across the nearly level tracts of the Wisconsin drift-sheet, and through several minor terminal moraines, until it finally breaks through the large Shelbyville moraine south of Charleston in a clear-cut youthful gorge a hundred feet or more in depth. From this point it continues a more quiet, meandering stream across the plains of the Illinoian drift, to its debouchure into the Wabash River, near Vincennes, Indiana.

Through the early part of its course the Embarras makes its way, leisurely in dry weather, but rapidly in rainy weather, along open, stream-made ditches, or in semi-canals opened by dredging-shovels, in a channel not large enough to carry the flood waters. The stream can hardly be said to have a valley, only a channel, in this part of its course, but after twenty-five to thirty miles have been covered the ditch has become enlarged and a valley formed, which gradually becomes wider and deeper until the moraine is reached. During all this distance extreme youth is a chief characteristic; the valley walls are very steep—so steep, in fact, that landslides are common, and the side streams are short. The main valley attains a depth of seventy-five or eighty feet before it reaches the moraine and is cut in the drift; but occasionally bed-rock is reached, and at such places the valley often narrows to a few feet, and the stream goes through a little rock-floored gorge with rapids or tiny cascades. In the moraine the valley is perceptibly deeper, and near the southern margin of it attains a depth of over one hundred feet, while at several points within the ten or twelve miles through the moraine the water runs on a rock floor, being definitely constricted within a rock gorge at two points.

As the stream comes out upon the older drift, the valley decreases markedly in depth, and increases slightly in width.

The decrease in depth is due, of course, to the absence of the newer drift-sheet and its thickened border, the moraine; the slight increase in width may doubtless be ascribed to the same cause. The valley continues to widen as the stream increases in size, but does not deepen much in the fifty-mile remainder of its course. Its fall is about that of the general slope of the land. Very rarely does the stream touch bed-rock, and at no point is the valley perceptibly constricted because of encountering the more resistant layers. In low water the stream quietly meanders along to its mouth. At a number of points within the first ten miles south of the moraine opposite valley bluffs are apparently of different heights. This was discovered to be due to the fact

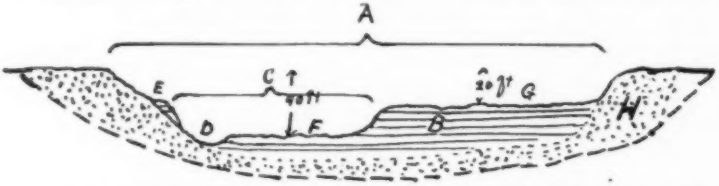

FIG. 2.— - - -, supposed boundary of preglacial valley; *A*, interglacial valley filled with; *B*, Wisconsin overwash material; *C*, present valley — postglacial; *D*, present stream bed; *E*, remnant of terrace on east side; *F*, present flood plain; *G*, second bottoms; *H*, Illinoian drift sheet. Vertical exaggeration about 25.

that the present gorge-like valley is within an older, more mature valley, whose sides are reached by the inner valley only on the east, and not continuously there. Hence along the west side there are practically two continuous bluffs, the inner one being from a few rods to three-fourths of a mile within the outer one. But on the east side the stream has pushed its inner bluff much nearer the outer one, reaching it at a number of points and blending with it in one continuous descent from the uplands to the present flood-plain. Where this stage has not been reached there are two bluffs on the east side, as on the west, but they are rarely far apart. When the bluffs have coalesced on one side and not on the other, opposite bluffs seem to stand at discordant levels. Fig. 2 illustrates the case. The second or outer bluffs often have a scarp nearly as steep as will stand, say 20–25°, but are usually of gentler slope.

In the latitude of Bradbury, some three miles south of the outer margin of the moraine, the second bluff attains nearly the same height above the first as the first does above the stream. Farther north the first bluff rises higher with reference to the stream and the outer bluff, until, near the moraine, the second becomes almost imperceptible, while farther south the first gradually decreases in height until it becomes practically *nil*. Fig. 2 is a cross-section, somewhat idealized, about opposite Bradbury, at a point where the two eastern bluffs coalesce. Fig. 3 is a bird's-eye view much conventionalized, of the conditions along the west side of the stream, as discussed above.

What is the relation of all this to glaciation? Evidently there are two periods of erosion represented. Is one postglacial? Where, in time, is the other? The nature of the materials in the two sets of bluffs and their relation to surrounding features alone can solve the problem.

Certainly there must be a preglacial valley somewhere near this present stream, unless the whole plan of the preglacial drainage has been upset. The Ohio, Mississippi, Illinois, and lower Wabash in this latitude are, in general, about where they were in preglacial time; hence the general direction of other large streams must be similar to that of their earlier courses, but they are not necessarily in exactly the same beds. The older drift, according to the records of borings and coal shafts, and the exposed sections in stream and railroad cuts, is from twenty to fifty feet thick, rarely more, often less. Between the outer or second bluffs which continue down the stream is a valley, increasing from a mile to three miles in width, and in the deeper portion of its cross-section about fifty feet deep, rarely revealing bed-rock in its floor or sides. Both are practically of continuous drift, corresponding in composition, physical characteristics, and state of weathering with the general drift-sheet on either side. The valley may be followed for fifty to sixty miles with no material change of character, so far as these features are concerned.

There are three time-periods to be considered in the solution of the origin of the valley in question. First, is it a preglacial valley? Second, was it formed since the retreat of the last ice-

sheet? Third, is it interglacial, formed after the advance of the ice that left the Illinoian and before that which left the Wisconsin drift? If it can be shown that the valley is neither preglacial nor postglacial, but is subsequent to the deposition of the Illinoian drift and prior to that of the Wisconsin, its position will be established. The three possibilities will be taken up in the order mentioned.

Since this valley, walled by the second bluffs, is cut in the Illinoian drift-sheet, it must have been formed subsequent to the laying down of that till-sheet. The character of the walls also precludes the possibility of its being due to rejuvenation

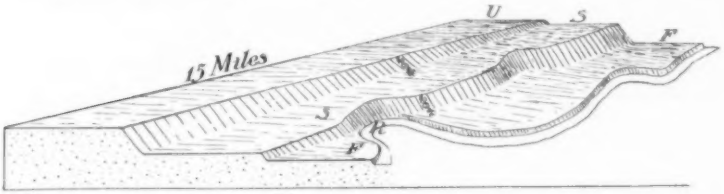

FIG. 3.—Looking N. W. from above east bluff at south end of the Wisconsin overwash in the interglacial valley. R = Embarras River, F = present flood plain, S = "second bottoms"—the terrace top, U = upland surface. Vertical scale very greatly exaggerated.

just prior to the first advance of the ice, as may be the case with those gorges cut in rock, but more or less filled with drift of a late age, such as have been reported in New York. Again, since the valley is so rarely cut down to bed-rock, when the latter is usually very near the surface outside the valley, it is probably in a preglacial, well-matured valley, whose limits are reached only when the present valley encounters ledges. Furthermore, since the valley in the Illinoian drift apparently lies within the preglacial valley, the latter must have been nearly, but not completely, filled and obliterated by the drift-sheet of this early ice invasion. Had it been completely filled, how could the stream now be so continuously within it? It is also true that no large percentage of the drift filling has been subsequently removed, else the walls of the preglacial rock valley would have been more frequently discovered. Likewise, it is reasonable, if not imperative, to suppose

that when the valley in the Illinoian drift was first formed it extended to a greater depth than the present stream has cut, because the latter, in the few miles of double gorge, is not yet running on Illinoian drift, not having succeeded in cutting through a subsequent filling of the valley in the Illinoian.

This leads to a consideration of the nature of the inner, lower bluffs which accompany the present stream some miles beyond the terminal moraine, and are represented by the second bottom terrace front in Fig. 3, *S*. They are of gravels and sands and, farther south, clayey, fine sands, and partially sorted and stratified drift material corresponding in composition and stage of weathering with that of the earlier Wisconsin, being similar also to deposits on the uplands spread out as an apron in places along the southern margin of the moraine. The second bottoms between the inner and outer bluffs on each side of the stream, where they are not blended into one bluff, are made of the same materials. Wells, on these bottoms, show a section of the same materials to a depth of fifteen to thirty feet. No deeper wells were found in it. Furthermore, the relation of this terrace material, thick near the moraine and feathering out to nothing southward, points to the same conclusion—namely, that the materials of the walls of the inner gorge are layers of overwash material carried out beyond the terminal moraine by the overloaded stream flowing from the melting ice, and deposited by that stream in order to aggrade its course, and thus increase its carrying power to a strength equal to its remaining load. Since this material is of Wisconsin age and is laid down within a valley already formed, that valley cannot be postglacial. The third and only remaining alternative is that the valley represented by the outer bluffs is one formed between the deposition of the Illinoian and that of the Wisconsin drift-sheets, and hence may be called an interglacial valley. Its width and general maturity differentiate it from the known postglacial valleys, while its relative lack of greater maturity, even though in unconsolidated materials, declares it not to belong to the preglacial drainage. The same facts speak for an interglacial time period considerably longer than the postglacial period has been.

Subsequent to the formation of the overwash plain in the interglacial valley and the associated retreat of the ice, the habit of the stream has been changed, because its load has been greatly reduced. Probably its volume has also been somewhat cut down, but not to correspond with the reduction in burden; hence, whereas the stream was aggrading its course during the Wisconsin stage, it has been degrading during the postglacial stage, and has so far succeeded in removing the previously deposited material that the stream now flows in a gorge, a half mile or more in width. The stream is still widening this valley, and the second bottoms (Fig. 2, *G*) still remain to be removed.

The second bottoms constitute terraces of better agricultural soil than that of the vicinal upland. They correspond in orign with those described by early writers in many New England valleys, and especially those in the Connecticut and tributaries so thoroughly studied recently by Professor W. M. Davis. They may be correlated with many terraces in Illinois valleys, because nearly all streams heading on the new drift and flowing out through the moraine are terrace-bordered. The conditions differ to some extent from those reported by Professor Davis in that the postglacial excavation has not proceeded sufficiently as yet to encounter the walls and floors of the old valley. Therefore there are no defending ledges, no series of terrace steps, and very few cusps. The stream has cut back as far, or a little farther, each time than on the previous swing, and hence there is one long step from the second bottoms or terrace-top to the present flood-plain. It is unfortunate that more attention has not been given to the terraces of the Illinois, Iowa, and Wisconsin streams. There are many such terraces, and no doubt a careful study of them would yield valuable returns.

Summary.—The history of the present Embarras River valley is a complex one. North of the moraine it is entirely postglacial, and probably bears little relation to its precursor of interglacial time, still less to the preglacial valley. Very likely near the moraine and in it where the valley is deepest the stream has cu its recent channel mostly in the filling of a former valley, but the occurrence of occasional rock-ledges witnesses to the errors of

the stream in attaining its former course. Farther back from the moraine, even to the stream's sources, the drift is so deep and the channel is so shallow that the absence of bed-rock in the bottom of the valley proves nothing as to the position of the earlier stream and its valley. South of the moraine the till is much thinner, and a valley with such depths as those of the Embarras would often, if not almost constantly, reach bed-rock, were it not within an earlier valley. Hence there was, first, a broad, well matured preglacial valley similar to those at present in nearby carboniferous rock in unglaciated parts of Indiana, Kentucky, and southern Illinois. Second, this valley was nearly filled with drift of Illinoian age. Third, after the retreat of the ice of the Illinoian stage and before the Wisconsin invasion, a valley was excavated in the above-mentioned filling. This probably extended some distance north of the present terminal moraine, possibly as far as the present sources of the Embarras. Fourth, this interglacial valley was partly filled with overwash material (entirely filled, north of the moraine, with drift) of Wisconsin age. And, fifth, the present youthful postglacial channel has been cut in the filling of the interglacial gorge, but the process has not gone far enough to reach bed-rock where the stream is fairly within the earlier valleys.

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Reviews.

SUMMARIES OF PRE-CAMBRIAN LITERATURE FOR 1902–1903. II.

[*Continued from p. 62.*]

C. K. Leith.

A. P. Coleman and A. B. Willmott. "The Michipicoten Iron Ranges." "Geological Series," *University of Toronto Studies*, 1902, pp. 39–83. See also *Report of the Bureau of Mines*, Ontario, 1902, pp. 128–51.

Coleman and Willmott describe and map the Michipicoten iron ranges. The rocks are classified as follows:

Archæan	Laurentian	Gneisses and granites
	Upper Huronian	Basic eruptives
		Acid eruptives
		Doré conglomerate
	Lower Huronian	Eleanor slates
		Helen iron formation
		Wawa tuffs
		Gros Cap greenstones

The Gros Cap greenstones are basic eruptives with ellipsoidal structure corresponding in position and character to the Ely greenstones of the basement complex of the Vermilion district of Minnesota. They are in part basal to the other rocks of the district, but in part also they are interbedded with the rocks of the Helen iron formation. The Wawa tuffs are acid schists having the composition of quartz-porphyry or felsite, usually in the form of tuff, ash, or breccia, and sometimes show stratification, taken to indicate deposition by water.

Slates of distinctly sedimentary origin, occurring in thin bands near Eleanor Lake and called the Eleanor slates, are referred to the Lower Huronian. Their relations to the Helen iron formation are not known.

The Helen iron formation, 500 feet thick, comprises banded granular silica with more or less iron ore, black slate, siderite with varying amounts of silica, and grünerite schist. All are found well developed at the Helen mine, and all but the grünerite schist have been found in the Lake Eleanor iron range also, while granular silica and siderite occur in large quantities in every important part of the range, though small outcrops sometimes show the silica alone. All of the rocks of the iron formation contain considerable amounts of iron pyrites. The grained silica and the granular silica is similar in certain respects to the jaspers and ferruginous cherts of the United States, and their origin is believed to be the same. They differ in being often soft, pulverulent, and brecciated. The black, graphitic slate, forming a thin sheet just under the iron range proper west of the Helen mine and at other points in the region, seems closely related to the granular silica, being composed of the same material with a large admixture of carbon which smears the fingers.

Iron ore is mined in the Helen mine, and this mine is described in detail. The

ore body is located at the east end of the deep Sayers Lake basin, partly above and partly below the old water level. The lake has now been drained, and the ores appear in a great amphitheater opening out to the west. The rocks immediately associated with the hematite are siliceous ore, ferruginous cherts, or grained silica rocks. These are mapped as immediately surrounding the iron ore, and also as forming for the most part the north wall of the amphitheater. The east wall of the amphitheater is composed of iron carbonate which shows gradations into siliceous ore and into hematite ore. The south wall is composed of Wawa tuffs.

The ores are believed to have resulted from the secondary alteration of an original iron formation consisting mainly of iron carbonate, grained silica, and limestone, in part interbedded with the Wawa tuffs, but mainly deposited above them. The iron formation and the tuffs were folded up together, with the result that the tuffs were formed into a trough underlying the iron formation, and the iron formation within this trough was folded and brecciated. Percolating waters then altered the iron carbonates. Probably the chief solvent of the carbonates was acid ferric sulphate or sulphuric acid resulting from the oxidation of the iron pyrites, which are found in considerable quantity throughout the iron formation. The ore body has resulted directly from the alteration of iron carbonate, the oxidation of the iron sulphide having yielded but little ore. The oxidation of the iron took place where solutions of iron carbonate came into contact with waters bearing oxygen.

The principal areas of iron formation possibly bearing iron ore at Gros Cap, Sayers, and Boyer Lakes, just east of the Helen mine, around Brooks Lake, south of Long Lake, just east of Goetz Lake, in Parks Lake, and between Parks and Kimball Lakes.

The Upper Huronian rocks are represented principally by the Doré conglomerate, occurring typically at the mouth of the Doré River and thence eastward beyond Michipicoten Harbor, and to a less extent in other parts of the district. This conglomerate is unconformably above the Lower Huronian rocks of the district. It contains pebbles of granite, felsite, conglomerate, granular silica of the iron formation and breccia.

The Doré conglomerate is cut by acid intrusives in dikes and bosses. These are the latest rocks of the region.

The Laurentian granites and gneisses have not been studied in detail in the Michipicoten district, but their associations with both Lower and Upper Huronian prove them to be post-Huronian eruptive masses.

Comment.—As noted in the above paper, there is very close similarity in lithology and succession between the rocks of the Michipicoten district and the rocks of the Vermilion iron-bearing district of Minnesota, although described under different names. The rocks above called Lower Huronian and Upper Huronian are called respectively Archæan and Lower Huronian by the United States geologists.

There is substantial agreement in the matter of the origin of the ores in the two districts.[1] The Wawa tuffs are also similar to the Palmer gneiss of the Archæan of the Marquette district. The granites and gneisses described as Laurentian for the Michipicoten district are similar in character and relations to granites in United States districts referred to the Lower Huronian.

[1] J. Morgan Clements, "The Vermilion Iron-Bearing District of Minnesota, *Monograph XLVI, U. S. Geological Survey*, 1903; C. R. Van Hise, "The Iron-Ore Deposits of the Lake Superior Region," *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305-434.

A. P. COLEMAN. "Rock Basins of Helen Mine, Michipicoten, Canada." *Bulletin of the Geological Society of America*, Vol. XLIII (1902), pp. 293–304.

Coleman discusses the origin of the rock basins of Boyer and Sayer's Lakes of the Michipicoten district of Canada, the former containing the Helen iron-ore body. He holds the lake basins to have resulted from the solution of the iron-bearing rocks long before glacial time.

A. B. WILLMOTT. "The Nomenclature of the Lake Superior Formations." JOURNAL OF GEOLOGY, Vol. X (1902), pp. 67–76.

Willmott discusses the nomenclature of the Lake Superior formations, this being practically a consideration of Van Hise's "Iron-Ore Deposits of the Lake Superior Region."[1] He argues principally against the correlation of the Animikie series with the Upper Huronian of the original Huronian area. He states that there can be no doubt that Logan in 1863 included within his Huronian two series — the one typically represented by the banded jaspers, the other by the slate conglomerate and the jasper conglomerate. This has been uniformly followed from that time forward by all Canadian geologists, and by many American, the vertical green schists and their interbedded banded jaspers being considered Lower Huronian. Professor Willmott doubts the advisability of attempting the separation of the green volcanics and sediments, except in limited areas of economic value. Here each would be given formational names, just as Van Hise has done with the Ely greenstone and the Soudan iron formation. In other places the volcanics and eruptives will take the name of the sediment with which they are associated. The lowest sedimentary series of the Lake Superior region is the Lower Huronian. These sediments were included in the areas mapped as Huronian by Logan in 1863, and, although not actually found in place by him, were recognized from their fragments, and to him should be given the credit. As so used, the term "Lower Huronian" is nearly equivalent to the term "Archæan" as used by Van Hise, and the term "Upper Huronian" is equivalent to Van Hise's "Lower Huronian." Accordingly, the Animikie, or the Upper Huronian of Van Hise, is younger than the original Huronian series. That the Animikie is later than the true Upper Huronian or original Huronian may be shown in the following ways:

1. Stratigraphically it is the third series of sediments upwards from the bottom of the geological column in the Lake Superior region; the Upper Huronian is the second.

2. Lithologically, the two series are quite different, and so presumably are of different age. There is very little conglomerate at the base of the Animikie; in the Huronian the quartzites, slate conglomerates, and jasper conglomerates are of great thickness. The oolitic jaspers found in the Animikie are quite absent from the Huronian. The shales, so important in the Animikie, are almost unknown in the Huronian. The laccolitic sills of the Animikie are lacking in the Original Huronian.

3. Structurally, the two series are usually said to be alike in that both lie flat and undisturbed. While this is quite true of the Animikie, it is only partially true of the Huronian north of the Georgian Bay, and is untrue of the Upper Huronian about Batchawana and Michipicoten. Coleman[2] and Murray[3] have described cases of

[1] C. R. VAN HISE, "The Iron Ore Deposits of the Lake Superior Region," *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305–434.

[2] *Bureau of Mines, Ontario*, 1901, p. 189.

[3] *Geological Survey of Canada*, 1858, p. 95.

vertical dip within the so-called Original Huronian, and others have been observed by myself. These seem to occur around the outer portion of the Huronian basin, and more gentle dips obtain in the central part. Evidently the Huronian has been subjected to forces which the later Animikie has escaped.

4. Assuming that the large areas of eruptive granite-geisses in the Lake Superior region are of the same age, we find that the Upper Huronian has in many cases been pierced by them, but that the Animikie always overlies them.

A. P. COLEMAN. "The Huronian Question." *American Geologist*, Vol. XXIX (1902), pp. 325–34.

Coleman discusses the Huronian question, his argument being mainly against the correlation of the Animikie series of the Lake Superior region with the Upper Huronian series. Evidence that the Animikie is unconformable above his Upper Huronian series is summarized, and emphasis is placed on the points that both the Upper Huronian and the Lower Huronian differ lithologically from the Animikie; they are metamorphosed and schistose as compared with the Animikie; and they are much folded aad highly tilted, in marked contrast to the Animikie.

Comment.—For the most part the terms "Upper Huronian" and "Lower Huronian," as applied by Professors Willmott and Coleman to rocks *outside* of the part of the Original Huronian area of Logan on the north shore of Lake Huron, are to be correlated respectively with the "Archæan" and "Lower Huronian" of the United States geologists, and thus Van Hise's "Upper Huronian" or "Animikie" comes above their "Upper Huronian." For such areas, therefore, there is no marked difference of opinion as to the number and succession of series, but only difference in names. However, when it comes to the correlations of these series with the rocks of the Huronian series on the north shore of Lake Huron the difference is fundamental. Coleman and Willmott, in common with other Canadian geologists, apply the term "Upper Huronian" to the entire series north of Lake Huron mapped as "Huronian" by Logan, and apply the term "Lower Huronian" to underlying greenstones, green schists, and jaspers (as typically developed in the Michipicoten district). This Lower Huronian series, with the addition of certain "Laurentian" granites, corresponds approximately to what Van Hise, following the terminology of the U. S. Geological Survey, has called the "Archæan" in this and other parts of the Lake Superior region. But the sediments which Logan mapped as "Huronian," and which are classed as "Upper Huronian" by Willmott and Coleman, have been divided on the north shore of Lake Huron by Van Hise and Pumpelly, following Alexander Winchell, into the "Lower Huronian" and "Upper Huronian" series, the break being placed at the base of the Upper slate conglomerate, It is with these divisions of the Original Huronian series that the correlation of the Upper Huronian and the Lower Huronian series of the rest of the Lake Superior region has been made by Van Hise. Field work done on the north shore of Lake Huron during 1902 by Professors Van Hise, Seaman, and the writer presents further evidence of the correctness of this correlation. A full discussion of the evidence is not possible here, but it will be presented shortly in a general monograph on Lake Superior geology now in preparation.

ANDREW C. LAWSON. "The Eparchean Interval: A Criticism of the Use of the Term Algonkian." *Bulletin of the Department of Geology*, University of California, Vol. III, pp. 61–52.

Lawson criticises the use of the term "Algonkian." He emphasizes the importance of the interval, which he calls the Eparchæan interval, between the "Huronian'

and Animikie series, that is, between the Lower Huronian and Upper Huronian, of the United States Geological Survey, and argues that no one term such as "Algonkian" should include a break of this importance. It is proposed to restrict "Algonkian" to the Animikie and Keweenawan rocks, and to retain Dana's term "Archæan" for all rocks below the Animikie, *i.e.*, below the Eparchæan interval, and also to retain the terms "Laurentian" and "Huronian," as subdivisions of the Archæan, with the significance originally given them by Logan. The correlations of the Animikie with the Keewatin of Minnesota and with the Upper Huronian of Lake Huron is regarded as an error, because of dissimilarity in lithology, stratigraphy, and in relations to intrusives. Following Willmott and others, it is believed that the Animikie is younger than the (Upper) Huronian series of Lake Huron, and thus later than the Eparchæan interval. Emphasis is placed on the marked lithological similarity in the sedimentary series below the Eparchæan break in the Lake Superior and Lake Huron region, and the probable correlation of these rocks with the Original Huronian series. Summarized in tabular form, the correlation proposed is as follows:

Paleozoic.		Cambrian (Upper division or Potsdam only).
		Unconformity.
	Algonkian.	Keweenawan.
		Unconformity.
		Animikie = Penokee = Upper Marquette.
Eparchæan Interval.		
Archæan		Huronian = Upper Keewatin = Lower Marquette, etc.
		Unconformity.
		Laurentian, so called, granite gneisses, etc. (intrusive in the Ontarian) and the Carlton anorthosites.
	Ontarian	Keewatin = Lower Huronian = Crystalline schists of south shore invaded by granite gneisses.
		Unconformity.
		Coutchiching.

Comment.—Concerning the correlation of the Animikie with the Upper Huronian the comment on Professors Willmott and Coleman's articles, summarized on a preceding page, is pertinent. Dr. Lawson implies that the Animikie has been correlated by the U. S. Geological Survey with the entire sedimentary Huronian series of the north shore of Lake Huron, while it has been correlated only with the portion of this series above the limestone; and against such a correlation his argument loses some of its force. If the Keweenawan and Animikie series are not Cambrian, as they are held to be by Lawson, but are pre-Cambrian, as held by the U. S. Geological Survey, then Lawson's objection to the term "Algonkian," as replacing in part the old term "Archæan," would prevent its application even to the Animikie and Keweenawan rocks to which he restricts it. As already noted, the nomenclature of Lake Superior and Lake Huron series is being fully discussed in a general monograph on Lake Superior geology now in preparation. Arguments for the adoption and retention of the term "Algonkian" will be summarized, together with new arguments developed in recent field work.

C. R. Van Hise. "Geological Work in the Lake Superior Region." *Proceedings of the Lake Superior Mining Institute*, Vol. VII (1902), pp. 62–69.

Van Hise briefly sketches the history of geological mapping in the Lake Superior region, calling attention to the difficulty of preparing accurate maps, and concludes that the maps which have been published from time to time since the earliest map of Foster

and Whitney represent reasonably close approximations to the facts as then known, and that, notwithstanding their many imperfections, they have been of service at the time of publication.

J. E. SPURR. "The Original Source of the Lake Superior Iron Ores." *American Geologist*, Vol. XXIX (1902), pp. 335–49.

Spurr discusses the origin of the pre-Cambrian iron ores of the Lake Superior regions. He repeats his conclusion that the Mesabi ores have resulted from the alteration of a green ferrous silicate of the class of glauconite, and further states that his conclusion in reference to the Mesabi iron formation may be "probably applied to most of the other Lake Superior iron ores."

Comment. — This paper is practically a reply to a brief abstract published in the *Engineering and Mining Journal* of an informal talk given by the writer before the Geological Society of Washington. While fully agreeing with Mr. Spurr's major conclusion that the Mesabi ores have resulted from the alteration of ferrous silicate granules, the writer has emphasized certain facts which seem to prevent the application of the name "glauconite" to this silicate.[1]

As to the statement that conclusions applicable to the Mesabi ores apply to most of the other Lake Superior iron ores, presumably this is based on certain similarities in granules and concretionary forms to be observed in the iron-bearing rocks of the Mesabi and Gogebic districts. This similarity the writer has discussed elsewhere,[2] and believes it will afford no support for Dr. Spurr's somewhat sweeping statement.

C. K. LEITH. "A Comparison of the Origin and Development of the Iron Ores of the Mesabi and Gogebic Iron Ranges." *Proceedings of the Lake Superior Mining Institute*, Vol. VII (1902), pp. 75–81.

Leith compares the origin and development of the Gogebic and Mesabi iron ores. The ores of the two districts occur in the same geological horizon; they result from the alteration, under weathering conditions, of a ferrous compound of iron, through the agency of percolating waters, and are localized in channels of vigorous circulation of water. But the differences in the development of the ores of the two districts are important. The original ferrous compound of iron is mainly iron silicate in the Mesabi district, and iron carbonate in the Gogebic district, although both substances appear in each district. The localization of the ores in the Gogebic district during their concentration has been within clear-cut pitching troughs with definite shapes, while in the Mesabi district the very gentle folding of the iron formation, its fracturing, and the absence of intrusives combine to make the channels of vigorous flow within the iron formation most devious, resulting in the curious and exceedingly irregular shapes now to be observed in the Mesabi ore deposits.

The original ferrous silicate from which the ores develop in the Mesabi district is in minute homogenous granules, the form of which remains even after the substance is changed. Associated with these granules are undoubted concretions of iron oxide and chert with concentric structure. In the Gogebic district there appear numerous

[1] C. K. LEITH, "The Mesabi Iron-Bearing District of Minnesota," *Monograph XLIII, U. S. Geological Survey*, 1903.

[2] C. K. LEITH, "A Comparison of the Origin and Development of the Iron Ores of the Mesabi and Gogebic Iron Ranges." *Proceedings of the Lake Superior Mining Institute*, 1902, pp. 75–81. (See summary below.)

concretions with concentric structure, which Van Hise has shown to develop during the alteration of iron carbonate; and associated with these are rare granules of iron oxide and chert in varying proportions, which may represent altered ferrous silicate granules similar to those of the Mesabi district. Evidences of the existence of original ferrous silicate granules in the Gogebic district are not sufficiently numerous to warrant modification of Van Hise's conclusion that the ores have developed from the alteration of iron carbonate.

C. K. LEITH. "The Mesabi Iron-Bearing District of Minnesota." Monograph XLIII, U. S. Geological Survey, 1903.

Leith describes and maps the geology of the Mesabi district of Minnesota. The district is two to ten miles in width, extending from near Grand Rapids on the Mississippi River to Birch Lake, a distance of approximately one hundred miles. The main topographic feature is a ridge known as the Giant's (or Mesabi) Range, which extends the length of the district. The geologic formations represented in the district belong, in ascending succession to the Archæan, Lower Huronian, Upper Huronian Keweenawan, Cretaceous, and Pleistocene. They are all separated by unconformities. The core of the Giant's Range is formed by Archæan and Lower Huronian rocks, except for the portion in ranges 12 and 13, where Keweenawan granite forms the core. On the south flank rest the Upper Huronian rocks, containing the iron-bearing formation, with gentle southerly dips. The Keweenawan gabbro lies diagonally across the east end of the district.

The Archæan rocks consist principally of green rocks of great variety, including dolerites, metadolerites, basalts, metabasalts, diorites, and hornblendic, micaceous, and chloritic schists. The more massive rocks frequently have an ellipsoidal structure, which is characteristic of the green igneous rocks of other parts of the Lake Superior region. In addition to the green basic rocks, there are present small areas of granite and porphyritic rhyolite.

The Lower Huronian series consists of sediments and granite. The sediments are graywackes, slates, and conglomerates, all metamorphosed, with bedding and schistosity practically vertical. They may be as thick as 10,000 feet, but it is thought more probable that the thickness does not exceed 5,000 feet. The Lower Huronian sediments rest unconformably upon the Archæan rocks, as shown by basal conglomerates containing fragments of all the varieties of rocks found in the Archæan. The Lower Huronian granite forms the main mass of the Giant's Range westward from a point near the east line of Range 14 W. It is intrusive into both the Archæan rocks and the Lower Huronian sediments, and has produced strong exomorphic effects in both.

The Upper Huronian or Animikie consists of three formations — the Pokegama quartzite at the base, above this the Biwabik formation (iron-bearing), and above this the Virginia slate.

The Pokegama quartzite comprises vitreous quartzite, micaceous quartz-slate, and conglomerate. The thickness ranges from 0 to 500 feet, averaging about 200 feet. The conglomerate at the base indicates unconformable relations of the Pokegama formation to the Archæan and Lower Huronian rocks.

The Biwabik formation, the iron-bearing formation, comprises ferruginous, amphibolitic, sideritic, and calcareous cherts, siliceous, ferruginous, and amphibolitic slates, paint rocks, "greenalite" rocks, sideritic and calcareous rocks, conglomerates and quartzites, and iron ores. Cherts make up the bulk of the formation. The

original rock of the formation is shown to consist largely of minute granules of green ferrous silicate, thus confirming Spurr's conclusion. The material was called "glauconite" by Spurr, but is here determined to be a hydrous ferrous silicate entirely lacking potash, and thus not glauconite. It is named "greenalite" for convenience in discussion. The cherts and iron ores are shown to develop mainly from the alteration of the greenalite granules. The slates are in thin layers interbedded with the other phases of the iron formation. The paint rocks result from the alteration of the slates. The conglomerates and quartzites form a thin layer from a few inches to perhaps 15 feet or more in thickness at the base of the formation. They pass upward into ferruginous cherts of the iron formation rather abruptly, though usually at the contact the chert and quartzite are interleaved for a few feet. The conglomerate of the iron formation rests upon Pokegama quartzite, indicating a slight erosion interval between the Biwabik and Pokegama formations, although the interval is not shown by discordance in bedding, which is parallel in both. Heretofore the quartzite and conglomerate in the iron formation have not been discriminated from the rocks of the Pokegama formation. In the eastern portion of the range the iron formation is in contact with the Keweenawan gabbro and granite, and near this contact has suffered profound metamorphism. The characteristic rocks of this area are amphibole-magnetite-cherts. The thickness of the formation may vary from 200 to 2,000 feet. The average may be 1,000 feet.

The Virginia slate is essentially a soft slate or shale formation, but it contains graywacke phases, near its base a little limestone, and near its contact with the gabbro is metamorphosed into a cordierite-hornfels. The normal slate phases of the formation may be distinguished with difficulty in isolated occurrences from the slate layers in the Biwabik formation. The separation of the two is of importance to the explorer, and hence an attempt is made to determine criteria for their discrimination. The thickness of the Virginia formation cannot be measured within the district, but from analogy with the Penokee-Gogebic district and the extent of the low, flat-lying area south of the Mesabi range supposed to be occupied by the slate, the formation is believed to have a very considerable thickness. The slate grades, both vertically and laterally, into the Biwabik formation.

The entire Upper Huronian series is well bedded, conformable in structure (although having a thin conglomerate between the Biwabik and Pokegama formations), and dips in southerly directions at angles varying from 5° to 20°, and exceptionally at higher or lower angles. The series is gently cross-folded, and the axes of the cross-folds pitch in southerly directions. Accompanying the folding is considerable jointing, especially in the brittle Pokegama and Biwabik formations. Indeed, in these two formations the folding is brought about mainly through relatively minute displacements along joints, while in the Virginia formation the folding has taken place mainly by the actual bending of the strata.

The thickness of the Upper Huronian series within the limits of the district mapped may average about 1,500 feet; but if the total thickness of the slate formation outside the limits of the district be taken into account, the total thickness of the Upper Huronian series is probably several times this figure.

The relations of the Upper Huronian series to the subjacent formations are those of unconformity, as evidenced by basal conglomerates, discordance in dip, difference in amount of deformation and metamorphism, distribution of the series, and relations to intrusives.

The Keweenawan rocks consist of gabbro, diabase, and granite, all of which are intrusive into the rocks with which they come into contact. The north edge of the gabbro runs diagonally across the east end of the district from southwest to northeast, resting upon the edges of each of the members of the Upper Huronian series, and at Birch Lake against the Lower Huronian granite. North of the gabbro margin, in Range 12, are isolated exposures of diabase which may represent sills associated with gabbro intrusion. The granite forms the crest of the Giant's Range through Ranges 12 and 13. This granite has not heretofore been discriminated from the Lower Huronian granite. The exomorphic effect of the gabbro and the granite upon the Upper Huronian series has been profound.

J. MORGAN CLEMENTS. "The Vermilion Iron-Bearing District of Minnesota." *Monograph XLV, U. S. Geological Survey*, 1903.

Clements describes the geology of the Vermilion iron-bearing district of Minnesota. Elaborate general and detailed maps, accompanying this report, are based on field work by Clements, Van Hise, Bayley, Merriam, and Leith.

The district ranges from two to eighteen miles in width, and extends from a little west of Lake Vermilion in a direction a little north of east to Gunflint Lake on the international boundary, a distance of about one hundred miles.

The rocks of the district are described under the headings "Archæan," "Lower Huronian," and "Upper Huronian," representing series separated by marked unconformities.

The Archæan of the Vermilion district is divided into three formations, as follows, given from the base up: the Ely greenstone, the iron-bearing Soudan formation, and the granites of Vermilion, Trout, Burntside, Basswood, and Saganaga Lakes.

The Ely greenstones consist of basic and intermediate igneous rocks widely distributed in anticlinal areas, as shown by the distribution of the overlying sediments. They were originally rocks corresponding in character to intermediate andesites and basic basalts. They have been extremely altered, but retain in many cases in striking perfection the original structures, such as ellipsoidal parting, and spherulitic and amygdaloidal structures. A study of their various textures and structures shows that these greenstones are unquestionably of igneous origin, and are largely of volcanic character. Many of them have been rendered schistose by pressure. The greenstones have also been strongly affected by the contact metamorphism due to the intrusion of great granite masses. As a result of this intrusion, there have been produced from the greenstones amphibole-schists, which form a marginal facies of the greenstones, lying between them and the adjacent granites. The greenstones have also been metamorphosed by the Duluth gabbro of Keweenawan age, and granular rocks have thus been produced which in most cases show the original textures of the greenstones, but contain also a development of fresh biotite, hypersthene, brown-green hornblende, and magnetite.

The Soudan iron formation is widely distributed in the western part of the district, but is practically wanting in the eastern half. It is found mostly in narrow belts, which consist largely of greenstone so intimately associated with the iron formation that it has been impossible to separate them on the map. The formation consists of (1) a very subordinate fragmental portion made up of some conglomerate, clearly recognizable as having been derived from the underlying greenstones, grading up into sediments of finer character; and (2) lying above this fragmental portion, the iron-

bearing formation proper, which consists of siliceous rocks, largely white cherts — though varying in color from white, green, yellow, and purplish to black — with red jasper and carbonate-bearing chert, grünerite-magnetite-schist, hematite, magnetite, and small quantities of pyrite. These iron-bearing rocks are clearly of sedimentary origin. They do not now present their original characters, but are presumed to have been derived from rocks that were largely carbonate-bearing, ferruginous cherts. The relation of the iron formation to the adjacent greenstones is clearly that of a sedimentary overlying an igneous series. The few basal conglomerates of the iron formation that have been found consist of pebbles derived from the underlying greenstone, showing conclusively their relationship. This relationship is obscured, however, in most places, by the absence of the conglomerates, and by the fact that the iron formation has been very closely infolded in the greenstone. In consequence of the extreme folding and of the impossibility of determining different horizons in the iron formation, it has been impracticable to ascertain its thickness. The iron-ore deposits of the Vermilion district show a striking analogy with those of the Marquette district. Like them, they may occur in two positions with respect to the iron-bearing formation. They are found, first, at the bottom of this formation, and, second, within it, the ores in both cases being the same in character. The Ely deposits are typical of the deposits occurring at the base of the formation. They are found at the bottom of a closely compressed syncline of the iron formation where it lies in the relatively impervious greenstone. The source of the iron was, in the first instance, the Ely greenstone. From this it was removed through the action of water and collected in the Archæan sea to form the sedimentary deposits of the Soudan formation. After the folding of the formation this disseminated iron was carried by downward percolating waters into places favorable for its accumulation, such as the bottom of this synclinal trough, where it was precipitated by oxygen-bearing waters coming more directly from the surface. *Pari passu* with this precipitation silica was removed, affording space for the accumulation of the iron to form the ore deposits as now known. The Tower and Soudan deposits differ only in detail from the Ely deposit.

Granites, intrusive into the Archæan, occupy a wide area, and are named from the topographic features with which they are conspicuously associated. That these intrusives are older than the Ogishke conglomerate (Lower Huronian), which succeeds in age the Soudan formation, is shown conclusively by the fact that pebbles derived from them occur in this conglomerate. The general period of intrusion of all of these acid igneous rocks is placed between the time of the deposition of the latest sediments of the Archæan and that of the deposition of the earliest sediments of the Lower Huronian series.

The Lower Huronian occurs in two detached areas, one of which, known as the Vermilion Lake area, extends from the western limit of the area mapped, in the vicinity of Tower, to within about eleven miles of Ely on the east, and the second of which, known as the Knife Lake area, begins about seven miles west of Ely, and extends eastward to the eastern limit of the area mapped. At the base of the series there lies a great conglomerate, known as the Ogishke conglomerate, containing pebbles and finer detritus from all of the rocks of the Archæan. Above this conglomerate, in the eastern portion of the district, there are found in a few localities small masses of the iron-bearing Agawa formation. This formation is petrographically the same as the Soudan formation. In it, however, there is in places a development of the carbonate-bearing facies. No iron ores have been found in it. Overlying the Ogishke conglomerate, in the

western portion of the district, and the intervening iron-bearing Agawa formation where present in the eastern portion of the district, there occurs a thick series of slates of varying character, to which the name "Knife Lake slates" has been given. These slates have been very closely folded, and have been more metamorphosed where intruded by granites of Giant's Range, Snowbank Lake, and Cacaquabic Lake, and by the Duluth gabbro. These igneous rocks occupy a considerable area, and their intrusive relation to the Lower Huronian are unquestionable. The Lower Huronian sediments now stand nearly vertical.

The Upper Huronian or Animikie series is found in the extreme eastern portion of the district, where it is continuous with the Animikie of the Mesabi district to the west and Thunder Bay to the east. At the bottom of the series occurs an iron-bearing formation known as the Gunflint formation. Above this occurs a great slate-graywacke formation, to which the name "Rove slate" has been given. The Gunflint formation is correlated with the Biwabik formation of the Mesabi district. It has a very limited development in the Vermilion district, and its most interesting phases are especially well developed in the vicinity of Akeley Lake. In general the formation has a monoclinal dip to the south-southeast at a low angle. It has been extremely metamorphosed by the Duluth gabbro, and where most metamorphosed the rocks are composed of coarsely crystalline bands of quartz, of varying width, alternating with coarsely crystalline bands of magnetite ore reported to vary from one inch up to ten or twelve feet in thickness, and of bands of dark-green, brown, or black rocks that consist of combinations of quartz, augite, hypersthene, hornblende, olivine, and magnetite as the principal minerals, but associated occasionally with some ferruginous carbonate, actinolite and grünerite.

The Duluth gabbro and the Logan sills, referred to the Keweenawan, occur in the eastern portion of the district. The gabbro is found to metamorphose all of the sediments already enumerated, and is thus shown to be one of the youngest rocks of the district. It is also found to be intrusive in the Keweenawan volcanics. A number of facts are enumerated to show that the gabbro and the Logan sills are of essentially the same petrographic character, although they exhibit minor differences that are readily explicable when one considers the relative amounts of the two rocks. After a consideration of these facts, and of the stratigraphic relationship of the rocks, the conclusion is reached that the gabbro and the sills are of essentially the same composition and age, having been derived from the same parent mass of magma. In certain localities in the Duluth gabbro there are found masses of titaniferous magnetite of varying but small size with some associated minerals. These masses grade into the surrounding gabbro, and were formed as the result of processes of segregation.

Cutting the Duluth gabbro are acid dikes and dikes of basalt and diorite.

The entire district has been much folded and metamorphosed, resulting in a marked north of east and south of west trend of the Archæan and Lower Huronian formations, marked principally by schistosity.

Comment on the Vermilion and Mesabi Reports.— Detailed work in these districts has developed a number of points bearing on the general stratigraphy and correlation of the rocks of the Lake Superior and Lake Huron districts.

In the Vermilion district the rocks now called Lower Huronian had previously been referred to the Upper Huronian by the U. S. Geological Survey, and the sedimentary Soudan iron formation, now mapped as Archæan, had previously been called Lower Huronian, and separated from the greenstones and granites supposed alone to

represent the Archæan. The Lower Huronian and Archæan of the present report correspond approximately with the Upper and Lower Keewatin of the Minnesota Survey, although there are minor differences in the reference of the several geological units to these divisions.

In the Mesabi district the rocks underlying the Animikie of the Upper Huronian had previously been lumped together as Archæan by the U. S. Geological Survey. They are now shown to be divisible into (1) a sedimentary formation, referred, with its associated intrusives, to the lower Huronian, showing remarkable similarity in lithology and structure to the Lower Huronian of the Vermilion district; and (2) an igneous series, referred to the Archæan, with marked similarity to the igneous rocks of the Archæan of the Vermilion district. The Lower Huronian and Archæan thus correspond roughly to the Upper and Lower Keewatin of the Minnesota Survey. This division of the Keewatin was not made in the Mesabi district by the Minnesota Geological Survey, although Dr. Grant noted the occurrence of rocks characteristic of the two divisions, and suggested the possibility of their separation.

The correlation of the Animikie series of the Vermilion and Mesabi districts with the Upper Huronian series of the north shore of Lake Huron is the same as in previous reports of the U. S. Geological Survey, and is the feature of the correlation which has been severely criticised by Canadian and other geologists, including Coleman, Willmott, Winchell, and Lawson, who hold the Animikie to be unconformably above the original Huronian series of the north shore of Lake Huron, from which the term "Huronian" comes. Comments on their arguments are made in connection with summaries of their articles on a preceding page.

The reference of the sedimentary Soudan iron formation to the Archæan, instead of including it in the Huronian and thus making a threefold division of the Huronian, as is now possible in the Marquette district, has also been criticised. The defense of such a use of the term "Archæan" involves a discussion of the principles of pre-Cambrian nomenclature not here warranted. Such a discussion will be made in a final monograph on Lake Superior geology now in preparation by the U. S. Geological Survey.

N. H. WINCHELL. Some Results of the Late Minnesota Geological Survey. *American Geologist*, Vol. XXXII (1903), pp. 246–53.

Winchell summarizes some results of the work of the late Minnesota Geological Survey. Those referring to the pre-Cambrian are as follows (the numbers are Professor Winchell's):

5. The discrimination of two iron-bearing formations in northern Minnesota, thus separating the Mesabi range stratigraphically from the Vermilion. This observation was continued into Wisconsin and Michigan by a visit to those states, and the same dualty was pointed out in the iron regions of those states, and was announced for the first time in the Minnesota report for 1888. It has since been discovered that there is still a third iron horizon in northeastern Minnesota, not mentioning the titanic iron ore of the gabbro. It is the upper Keewatin, the others being in the Lower Keewatin and the Taconic.

6. The separation of the Archæan of Minnesota into two non-conformable parts, viz., the Upper and Lower Keewatin, with a great basal conglomerate between them.

7. The determination of the oldest known rock of the Lake Superior region, a greenstone called Kawishiwin, the bottom rock of the Keewatin, the supposed earliest crust of the globe.

8. The great quartzite formation, which cuts quite a figure in the geology ot Wisconsin and Minnesota, is nonconformable upon the Animikie, and is a member of the fragmented beds of the Keweenawan. This has been named "Sioux quartzite," "Baraboo quartzite," and "New Ulm quartzite." It is that which contains the red pipestone (catlinite) in southwestern Minnesota. It is the western representative of the Potsdam sandstone, of Potsdam, N. Y. This quartzite seems to be the representative of the Middle Cambrian, as the Beckmantown is of the upper Cambrian.

9. The origin of the Mesabi iron ore is referred to a greensand, which has been altered, affording iron ore by concentration of the iron in certain favorable positions. Cotemporary with this alteration was a concentration of silica, and this was increased by oceanic precipitation. The original greensand was found to become pebbles, and to increase into angular masses that were neither sand nor pebbles, but rather breccia. These breccia masses have at first an amorphous crystalline texture and grade into a form of the iron-bearing rock which was named "taconyte," and the whole was referred to volcanic action, being different forms of suddenly cooled volcanic glass and rhyolite, broken and distributed by beach action. While this volcanic débris was undergoing this transformation, great quantities of silicia were set free from the glass; but this silicia immedially saturated the débris, producing spotted jasperoid, taconyte, and sedimentary jaspilyte.

Having reached this result on the Mesabi Range, it opened the door to the understanding of the iron ores of the Vermilion Range, and at once the rhyolitic forms and all the igneous associations of those ares with basic igneous rocks were elucidated, thus confirming Wadsworth's idea of the igneous origin of the jaspilytes of the Marquette region — rather the igneous origin of the rock which later was changed into jaspilyte.

10 and 11. After prolonged field examination, the Minnesota Survey reached the conclusion that the granites of the Archæan grade into gneiss, the gneiss into micaceous gneiss and mica schist, and finally into less and less metamorphic rocks that show a plain fragmental structure and sedimentary origin. There was found no exception among the Archæan granites. The granites are of two dates of formation — one at the close of the Lower Keewatin, and one at the close, or after the close, of the Upper Keewatin. A later granite, associated with the gabbro, and grading into it, is of the Keweenawan, and another did not spring from a deep source, but is a surface product of metamorphism carried to the extreme of fusion, on clastic materials that were later than the basal greenstones. Adventitiously they form intrusions in some of the later (and especially into the clastic) greenstones, but they are not known to penetrate the oldest greenstones. Tentatively the alkaline and the acid siliceous elements in these early sediments were supposed to have been derived from the atmosphere, as the basal crust could not have afforded them.

In the same manner the gabbro, which becomes acid and grades into syenite, was derivdd from the metamorphism and fusion of the greenstone with their clastic variations. Diabase was found to pass insensibly into gabbro; but, on the other hand, it is also certain that it was the original form of all igneous greenstones, and that it must have had, and still has, a deep-seated source.

These belts of intensest metamorphism, whether productive of granite or of gabbro, have a parallelism with each other, and with the northwestern rim of the great synclinorium of the basin of Lake Superior, marking successive continental folds, in harmony with a system which continued through Archæan and Taconic time, and even into the Upper Cambrian.

Comment.—Conclusions 5 and 6 are essentially in accord with conclusions reached by United States geologists who have worked in this area, although differing in nomenclature and minor points. The same may be said of Conclusion 7 in the matter of a greenstone being the oldest rock in the state, although Professor Winchell is alone in calling it the earliest crust of the globe. From Conclusions 8, 9, 10, and 11 the United States geologists dissent *in toto*. Adequate discussion of these conclusions would involve covering the entire range of Minnesota geology. The reader is referred to *Monographs XLIII*,[1] and *XLV*,[2] and to pp. 305-434[3] of Part III of the *Twenty-first Annual Report of the U. S. Geological Survey* for such a discussion.

N. H. WINCHELL. "Sketch of the Iron Ores of Minnesota," *American Geologist*, Vol. XXIX, pp. 154–62.

Winchell briefly describes the iron ores of Minnesota, and incidentally sketches their geological relations. No new points are added to those previously presented.

ROBERT BELL. "Report on the Geology of the Basin of Nottaway River." *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Part K, 1902.

Bell describes and maps the geology of the basin of the Nottaway River. Granites and gneisses referred to the Laurentian occupy the larger portion of the area. They are for the most part intrusive into the crystalline schists referred to the Huronian. Huronian rocks occur principally in a large area that is near the center of the region, and in small areas north of the center of the region and south of Lake Mistassini in the eastern part. The large tract of Huronian rocks forms a part of the great belt of Huronian rocks extending continuously from the eastern side of Lake Superior to Lake Mistassini, a distance of seven hundred miles. The Huronian may be grouped in three classes, namely: (1) crystalline schists, together with some other rocks forming a comparatively small proportion of the same series; (2) massive greenstones; and (3) granites. The schists embrace a considerable variety, but the greater part of them are dark green and hornblendic or dioritic, and they often pass into more or less massive greenstones, so that it becomes difficult to map the two varieties separately. Dolomite, quartzite, arkose, conglomerate, and agglomerate are exceptional occurrences.

J. BURR TYRRELL AND D. B. DOWLING. "Reports on the Northeastern Portion of the District of Saskatchewan and Adjacent parts of the Districts of Athabasca and Keewatin," *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Parts F and FF, 1902. With map.

Tyrrell and Dowling report on the northeastern portion of the district of Saskatchewan, and adjacent parts of the districts of Athabasca and Keewatin, comprising an area adjacent to the north end of Lake Winnipeg. The east, northeast, and northern

[1] C. K. LEITH, "The Mesabi Iron-Bearing District of Minnesota," *Monograph XLIII, U. S. Geological Survey*, 1903.

[2] J. MORGAN CLEMENTS, "The Vermilion Iron-Bearing District of Minnesota," *Monograph XLV, U. S. Geological Survey*, 1903.

[3] C. R. VAN HISE, The Iron Ore Deposits of the Lake Superior Region, *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305–434.

portions of the area mapped are occupied by Laurentian and Huronian rocks, of which the Laurentian rocks are in the larger areas. They consist of granites and gneisses, some of which are intrusive into the Huronian, and some of which are probably basal to it. Huronian rocks are found in small areas at Cross Lake, at Pipe Lake, and in the large area extending from Wekusko Lake to Athapapuskow Lake. They consist of conglomerates, quartzites, basic eruptives, and greenstones, and altered schists, similar to rocks of Lawson's Keewatin and Couchiching series.

A. P. Low. "Report on the Geology and Physical Character of the Nastapoka Islands, Hudson Bay," *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Part DD, 1903.

Low describes the geology of the Nastapoka Islands, Hudson Bay. The rocks forming the islands are in descending order as follows:

	Feet
1. Rusty-weathering, dark gray siliceous rock containing ankerite (carbonate of iron and magnesia, and magnetite	20–100
2. Dark gray siliceous rock containing magnetite, with small quantities of ankerite	50–250
3. Red jaspilyte rich in hematite ore	10–100
4. Red jaspilyte poor in hematite ore	5–20
5. Purple, or greenish-weathering, dark green, graywacke shales	10–70
6. Red jaspilyte poor in hematite ore	0–5
7. Light greenish-gray sandstone and shale	10–300
8. Fine-grained dolomite	0–50

There is a general dip toward the westward, or toward the sea, of from 5° to 15°. There are north-and-south faults, the upthrow being almost on the west side, with the result that the rocks appear in north-and-south ridges. The displacement is small and rarely exceeds one hundred feet. Another system of faults lies transverse to the first system.

Large areas of similar unaltered sedimentary rocks occur throughout the peninsula of Labrador, and are probably the equivalents of certain of the iron-bearing series about Lake Superior and of those to the westward of Hudson Bay, hand specimens from these localities being undistinguishable. On former maps of portions of the peninsula of Labrador, the areas of rocks belonging to this formation have been colored as belonging to the Cambrian formation, and in the earlier reports on this region the rocks were thought to be a part of that system, owing to their unaltered condition, in contrast with all the other rocks of that vast area that were either crystalline granites and other irrupted rocks, or crystalline schists and gneisses, so completely metamorphosed as to have lost all trace of their original sedimentary nature, if any were sediments. These highly crystalline rocks were classed as Laurentian or Huronian, and were considered to be much older than the unaltered rocks of the so-called Cambrian areas. More extended and closer study of both the unaltered and crystalline rocks, and of their relations to one another, has changed the views of the writer; and he now considers the unaltered, so-called Cambrian rocks to be the equivalents of many of the gneisses and schists classed as Laurentian (Grenville series), and the Huronian areas of the Labrador peninsula to represent a portion of the unaltered rocks and their associated basic eruptives (traps, trap-ash, etc.), altered by the irruption of granite and rendered schistose by pressure The granites which have been classed as typical Laurentian, always cut and alter the bedded rocks wherever seen in direct contact with them, and are consequently newer than the latter.

During the past season very thin layers of carbon with some resemblance to organic forms were found in the sandstones of Cotter Island; these have the appearance of lowly organized plant life, lower than the known fossils from the lowest beds of the Cambrian; and consequently this formation is older than the Cambrian. It is proposed, therefore to class these so-called Cambrian unaltered rocks as Laurentian, as they represent the oldest known sedimentary rocks in the northeast of America, and probably in the world.

West Virginia Geological Survey. Vol. I, Oil and Gas; Vol. II, Coal; and map showing the occurrence of coal, oil, and gas in West Virginia. By I. C. WHITE, State Geologist.

PROFESSOR I. C. WHITE, state geologist of West Virginia, has just issued a map showing the distribution of coal, oil, and gas areas in that state. The base of the map is topographic, with contours of 1,000 feet, and is, all in all, the most accurate map of the state which has ever been published. The map shows both the coal areas and the coal mines of the state. Of the former, the Pittsburg, the Allegheny-Kanawha, and the New River-Pocahontas are differentiated. In the aggregate, the coal areas cover nearly one-half of the state. The areas of natural gas and oil, though more restricted, are still extensive.

The map, just published, is a welcome supplement to the excellent volumes on Oil and Gas (Vol. I, issued in 1899), and Coal (Vol. II, issued in 1903). No state geological survey has issued economic reports of greater worth. While in the case of both volumes the treatment is primarily economic, the general structural relations of the Mississippian, Pennsylvanian, and Permian series, as developed in West Virginia, are clearly set forth.

R. D. S.

Geographic Influences in American History. By ALBERT PERRY BRIGHAM. The Chautauqua Press, 1903. Pp. x+366; 61 illustrations.

American History and its Geographic Conditions. By ELLEN CHURCHILL SEMPLE. Boston: Houghton, Mifflin & Co., 1903. Pp. 466; 16 maps.

THE above books are pioneers in a most interesting and important field, too long neglected. American history has been profoundly influenced by geological and geographical conditions. To ignore these controls is to make history very largely empirical. To recognize them is to go a long way toward making history a rational science. To

appreciate, for example, the geographic conditions which controlled every move of the contending armies of the Civil War in Virginia is to make intelligible a chapter of American history from which otherwise one gets but a confused, meaningless impression.

The scope of Professor Brigham's book is indicated by the chapter headings: "The Eastern Gateway of the United States;" "Shore-Line and Hilltop in New England;" "The Appalachian Barrier;" "The Great Lakes and American Commerce;" "The Prairie Country;" "Cotton, Rice, and Cane;" "The Civil War;" "Where Little Rain Falls;" "Mountain, Mine, and Forest." As these topics suggest, the author's view-point is always that of the geographer. The treatment of the subject is simple and somewhat popular, the book being designed primarily for a non-professional class of readers.

Miss Semple's book is a distinct contribution. The geographic influences which have shaped the trend of American history, from the discovery of the continent to the present, are treated in a scholarly and judicious manner. The inclusive character of the book is shown by the titles of the chapters: "The Atlantic States of Europe the Discoverers and Colonizers of America;" "The Rivers of North America in Early Exploration and Settlement;" "The Influence of the Appalachian Barrier upon Colonial History;" "The Westward Movement in Relation to the Physiographic Features of the Appalachian System;" "Geographical Environment of the Early Trans-Allegheny Settlements;" "The Louisiana Purchase in the Light of Geographic Conditions;" "Geography of the Atlantic Coast in Relation to the Development of American Sea Power;" "Geography of Sea and Land Operations in the War of 1812;" "Spread of Population in the Mississippi Valley as Affected by Geographic Conditions;" "Geographic Control of Expansion into the Far West: the Southern Routes;" "Expansion into the Far West by the Northern Trails;" "Growth of the United States to a Continental Power Geographically Determined;" "The Geography of the Inland Waterways;" "The Geography of the Civil War;" "Geographical Distribution of Immigration;" "Geographical Distribution of Cities and Industries;" "Geographical Distribution of Railroads;" "The United States in Relation to the American Mediterranean;" "The United States as a Pacific Ocean Power."

Miss Semple has been skilful in the selection of material from the great mass of scattered data. Irrelevant matters are invariably excluded, and the conclusions reached are generally fundamental. New light is

thrown on many topics. English success and French failure in North America are shown to have been largely due to geographic conditions. At the north the French followed every stream into the interior in quest of furs. "They spread themselves thin over an enormous area," and therefore failed. The Appalachian Barrier confined the English to the coast, and the many resulting advantages contributed to their success. It is popularly supposed that our possession of the Louisiana territory is due to a series of fortunate circumstances in European politics. Miss Semple shows that, once having passed the Appalachians, geographic conditions made it inevitable that the Americans should control the interior at least as far west as the Rockies.

The purchase of Louisiana was the occasion, not the cause, of the acquisition of the trans-Mississippi country. That must have come sooner or later. Even if the French had established themselves in Louisiana, they could not long have resisted the operation of geographic factors and the enterprising spirit of the western people, itself in part a product of environment. The trans-Mississippi region, hopelessly arid beyond the one-hundredth meridian, could never have supported a large enough population to resist the Americans, with whom the common navigation of the Mississippi would soon have brought them to blows. . . . . Had England conquered Louisiana from France—the chance which Napoleon feared—even her superior colonizing methods could not have made the country support a population large enough to cope with the thickly planted American settlements in the wide, rich, well-watered regions to the east. In a conflict between a cis-Mississippi and a trans-Mississippi power, the former had every geographical condition in its favor—coast-line, rivers, climate, soil, and habitable area. The Americans were destined to hold the West. The purchase hastened and facilitated the process.

The excellent discussion of the War of 1812 throws much light on a period which, to be understood, must be approached from the geographic side. Geographic conditions made this a frontier war and controlled all operations. The author does not overestimate the importance of the geographic view-point when she says:

The sea-fights of this war, if studied merely in their chronological sequence as presented in the ordinary school histories, leave only a confused impression, of which the student, young or old, retains little at all and less that is valuable. But an analysis of the geographical distribution of these engagements reveals a wide underlying system which explains their purpose and brings order out of an apparent chaos.

The Gadsden Purchase has been almost universally condemned as a purchase involving the payment of an enormous price for a small

tract of worthless land. Miss Semple maintains that because of the great strategic importance of the Gila River depression as a passway to the coast, money was never better spent.

Miss Semple believes the most potent factor in American expansion to have been the abundance of free land. The exhaustion of the supply has led to a recent exodus of westerners into Canada, over 50,000 going in the three years following 1899. It is pointed out that we must look to the recently initiated national system of irrigation in the arid West for the checking of this migration.

The arrangement of the matter in the book is not always the best, and a very few important topics are slighted. For instance, the discovery of gold in California does not receive due emphasis as a factor in American expansion. Such shortcomings are few, however, and the book is to be heartily commended to all students of geography and history.

H. H. B.

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